# A Housing Energy Management Program Report

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# ENERGY CONSERVATION - WINDOWS AND WINDOW TREATMENTS

Undertaken jointly by the Ontario Ministries of Municipal Affairs and Housing and Energy under the Housing Energy Management Program (H.E.M.P.)

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# ENERGY CONSERVATION - WINDOWS AND WINDOW TREATMENTS

## EXECUTIVE SUMMARY

The Ontario Research Foundation was commissioned by the Ontario Ministry of Municipal Affairs and Housing - Research and Development Section, to undertake a comprehensive review of information pertaining to the thermal performance characteristics of residential windows and window treatments. This report presents the results of this review.

The report opens with a discussion of the fundamental mechanisms of heat loss through windows. Air leakage and conductive heat transfer losses are considered, and the performance characteristics of single-glazed windows are reviewed in depth.

Means of reducing window heat losses are then investigated.

- The effectiveness of enhanced glazing systems as energy-saving window treatments is discussed in detail, with consideration given to the thermal performance properties of both conventional storm-window arrangements and factory-sealed multiple-glazed window units.
- The use of reflective films and coatings is reviewed. A discussion of novel 'heat mirror' technology is presented.
- The performance requirements and physical characteristics of movable window-insulating devices are examined in detail. Options for interior, exterior and inter-pane insulating treatments are described.

The first section concludes with a discussion of the performance testing of windows and window-insulating devices. Test procedures for the evaluation of the thermal performance properties and air leakage characteristics of window assemblages are submitted.

The second phase of the report, develops specific qualitative criteria necessary for the evaluation and rating of window glazing options and window insulating devices with respect

to energy and service performance. The alternatives are categorized as either a glazing option, which includes various glazing configurations, spacings and interpane gas fills; or window insulating devices, which include add-on or inter-pane enhancements. The latter group includes those devices intended to be used in conjunction with a particular glazing configuration to improve the thermal performance of the overall window system. The options in the glazing category are evaluated for performance of the glazing unit being considered, while the window insulation devices are evaluated for benefits that can be expected from the addition of that enhancement to a primary glazing. The latter evaluation does not include the effect of a primary glazing, and can be interpreted as a 'stand-alone' rating for that option. The tables are set up so that the value of Table II may be added to those of Table I to achieve cummulative performance values for a given combination.

The report concludes with a presentation of the relevant data in tabular form in Tables I and II, which summarize the criteria development and option evaluation section of the report.

TABLE I

Window Glazing Alternatives

| Type of Glazing (excluding sash or frame components) | 1983 Estimated Cost* ($/m²) | Comparative Energy Performance: Thermal Resistance RSI $W^{-1}.m^2.{}^{o}C$ | Comparative Energy Performance: Thermal Resistance R $Btu^{-1}.h.ft^2.{}^{o}F$ | Comparative Energy Performance: Shading Coefficient (total of glazing components) | Comparative Service Performance: Convenience | Comparative Service Performance: Durability | Comparative Service Performance: Maintenance |
|---|---|---|---|---|---|---|---|
| A. Single Glazing | | | | | | | |
| A.1 Clear single glass panel (5mm) | $19.00 | 0.16 | 0.91 | 0.94 - 1.0 | ● | ● | ◒ |
| B. Multiple Glazing | | | | | | | |
| B.1 Exterior storm window (operable) plus single glazing (air space 25-100mm) | $35.-50. | 0.35 | 2.0 | 0.85 - 0.92 | ● | ● | ● |
| B.2 Fixed double glazing ie: 2 single panels with 25-100mm air space | $35.00 | 0.35 | 2.0 | 0.85 - 0.92 | ● | ● | ◒ |
| B.3 Sealed insulating glass units double glazing | | | | | | | |
| - 6.3mm air space | $65.00 | 0.31 | 1.75 | 0.85 - 0.92 | ● | ◑ | ● |
| -12.5mm air space | 65.00 | 0.35 | 2.0 | 0.85 - 0.92 | ● | ◑ | ● |
| -19.0mm air space | 65.00 | 0.37 | 2.10 | 0.85 - 0.92 | ● | ◑ | ● |
| B.4 Sealed insulating triple glazed glass units | | | | | | | |
| - 9.6/ 9.6mm air spaces | $120.00 | 0.41 | 2.33 | 0.7 - 0.82 | ● | ◑ | ● |
| - 9.6/12.6mm air spaces | 120.00 | 0.46 | 2.61 | 0.7 - 0.82 | ● | ◑ | ● |
| -12.6/12.6mm air spaces | 120.00 | 0.50 | 2.84 | 0.7 - 0.82 | ● | ◑ | ● |
| C. Multiple Glazing - Gas Filled | | | | | | | |
| C.1 Sealed insulating glass with low conductance gas fill, double glazing | | | | | | | |
| - 9.6mm air space | $80.00 | 0.34 | 1.9 | 0.85 - 0.92 | ● | ◑ | ● |
| -12.6mm air space | 80.00 | 0.42 | 2.38 | 0.85 - 0.92 | ● | ◑ | ● |

Symbols

● Good

◒ Generally acceptable for amount of effort or time required for deployment and maintenance by consumers with a reasonable level of interest in window management.

◑ Durability of sealed unit generally guaranteed by the manufacturer for 5 years.

○ Poor level of performance or unreasonable degree of effort required for operation of option.

* Note: Glazing only, does not include sash, frame or installation costs for a standard sized window with nominal dimensions 940 mm x 1600 mm (Table I and Table II).

| Description of Option | 1983 Estimated Cost ($) Not Incl. Install. | Nominal R-value Option RSI $W^{-1}.m^{2}.°C$ | Btu⁻ |
|---|---|---|---|
| **A. Exterior** | | | |
| A.1. Exterior roll-down shutter: PVC or aluminum slats | $150. + | 0.19-0.28 | 1.1 |
| A.2 Exterior folding shutter with good edge seals - | | | |
| i) 25mm thick-extruded polystyrene/wood sandwich | $85.00 | 0.95 | |
| ii) 50mm thick-extruded polystyrene/wood sandwich | 95.00 | 1.82 | 1 |
| iii) 100mm tnick extruded polystyrene/wood sandwich | 105.00 | 3.54 | 2 |
| A.3 Exterior storm window - covering primary window frame. (25-100mm air space) | $35. - 50. | 0.19 | |
| **B. Between Glazings** | | | |
| B.1 White adjustable shades between glass eg: 'Pella Slimshade' | $65.00 | 0.078 | |
| B.2 'Beadwall' Zomeworks Corp. polyester beads blown into double glazed sealed unit(50mm) | $650.00 | 1.36 | |
| B.3 Polyester film with vacuum deposited coating used as centre-light in triple glazing eg: '3M Sungain Window Film' | $50.00 | 0.14 | |
| **C. Interior** | | | |
| C.1 Surface coatings - organic or inorganic | $45. - 75. | 0.11-0.16 | 0.6 |
| C.2 Interior shutters with good edge seals | | | |
| i) 25mm extruded polystyrene and wood sandwich | $40. - 250. | 0.93 | |
| ii) 25mm polyurethane and wood sandwich | $50. - 250. | 1.25 | |
| C.3 Interior quilted roller shades | $100. + | 0.7-1.0 | 3.9 |
| C.4 Insulating drapes with edge seal and liner | $70. + | 0.26-0.35 | 1.5 |
| C.5 Interior storm panels (vinyl, acrylic, polyester etc.) | $7. - 23. | 0.16-0.19 | 0.9 |
| C.6 Standard venetian blinds | $20. + | 0.05-0.07 | 0.3 |
| C.7 Standard weight drapes | $30. + | 0.05-0.12 | 0.3 |
| C.8 Standard roller blinds or shades | $5. - 25. + | 0.05-0.11 | 0.3 |

* Based on percentage of time user can be expected to deploy opt

**See legend in Table 1.

TABLE II

Window Insulating Alternatives

| Comparative Energy Performance | | | | | | Comparative Service Performance** | | | |
|---|---|---|---|---|---|---|---|---|---|
| dded by R hr.ft².°F | Usage Factor* | Effective R-value Added By Option After Discount Usage Factor Applied | | Air Tightness Rating of Entire System | Shading Coefficient (fully deployed) | Convenience | Durability | Maintenance | Comments |
| | | W⁻¹.m².°C | Btu⁻¹. hr.ft².°F | | | | | | |
| 1.6 | 0.67 | 0.12 - 0.18 | 0.72 - 1.04 | Improved | 0.4 - 0.07 | ◒ | ◒ | ◒ | - manually operated from interior |
| 4 | 0.67 | 0.62 | 3.51 | Improved | 0 | ○ | ◒ | ◒ | - manual operation |
| 34 | 0.67 | 1.18 | 6.72 | Improved | 0 | ○ | ◒ | ◒ | |
| 1 | 0.67 | 2.30 | 13.07 | Improved | 0 | ○ | ◒ | ◒ | |
| 1 | 1.0 | 0.19 | 1.1 | Improved | 0.85 - 0.92 | ● | ● | ● | |
| 44 | 0.75 | 0.059 | 0.33 | Not Affected | 0.18 | ◒ | ◒ | ◒ | - shades are manually adjusted |
| 7 (total unit) | 0.75 | 1.02 | 5.78 | Good | 0.1 - 0.25 (est.) | ◒ | ◒ | ◒ | - electric operation, started and stopped manually |
| 79 | 1.0 | 0.14 | 0.79 | Not Affected | 0.82 - 0.85 | ● | ◒ | ● | |
| 0.9 | 1.0 | 0.11 - 0.16 | 0.60 - 0.90 | Not Affected | 0.25 - 0.9 | ● | ◒ | ◒ | - should be protected from abrasion |
| 3 | 0.75 | 0.70 | 3.98 | Improved | 0 | ◒ | ◒ | ◒ | - manual operation |
| 1 | 0.75 | 0.94 | 5.33 | Improved | 0 | ◒ | ◒ | ◒ | |
| - 5.67 | 0.75 | 0.53 - 0.75 | 2.98 - 4.25 | Improved | 0.2 - 0.47 | ◒ | ◒ | ◒ | - manual operation |
| - 2.0 | 0.75 | 0.20 - 0.26 | 1.13 - 1.5 | Improved | 0.35 - 0.7 | ◒ | ◒ | ◒ | |
| - 1.1 | 1.0 | 0.16 - 0.19 | 0.9 - 1.1 | Improved | 0.90 | ◒ | ○ | ◒ | - susceptible to abrasion |
| - 0.4 | 0.67 | 0.03 - 0.05 | 0.20 - 0.26 | Not Affected | 0.55 - 0.64 | ◒ | ● | ● | |
| - 0.7 | 0.67 | 0.03 - 0.08 | 0.20 - 0.46 | Not Affected | 0.76 - 0.90 | ◒ | ● | ● | |
| - 0.6 | 0.67 | 0.03 - 0.07 | 0.20 - 0.39 | Not Affected | 0.25 - 0.70 | ◒ | ● | ● | |

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# PART I - HEAT LOSS THROUGH FENESTRATION

## 1. INTRODUCTION

Windows are the most vulnerable elements in a building envelope with respect to heat transmission. Generally lacking the insulative properties of surrounding wall and ceiling constructions, they act as 'thermal sieves' in the building shell, through which as much as 25-50% of a building's heat can be lost.

The solution to window heat loss lies not in the exclusion of windows from the building envelope, since, as architectural elements, windows perform several important functions. For instance, they allow the entry of natural light and ventilation; they provide a view to the exterior, and in some instances, they provide a means of access and egress. Windows also permit the ready entry of solar radiation into a building, and thus have the potential to reduce gross energy demands.

Window heat losses can best be combatted through the use of energy-efficient window units and window-insulating devices. These options are described herein.

## 2. HEAT LOSS

### 2.1 Mechanisms of Heat Transmission

The transmission of heat through materials can be described by three mechanisms: conduction, convection, and radiation. In each case, the second law of thermodynamics is obeyed; ie, heat transfer occurs when a temperature gradient exists, and its movement is always towards material or space having a cooler temperature.

Conduction is a process that occurs in solid, stationary matter. When a temperature differential exists within a medium, all parts of that medium will attempt to reach a constant temperature, and hence heat energy is transferred by molecular vibrations. In window systems, heat is conducted through glass, sash and frame components.

Convection is an alternative form of heat transfer that occurs in liquids and gases due to motion of the fluid or gas. Motion can be induced by an external agent such as a fan, or by density variations within the medium itself. Air convects heat readily, hence air spaces in window systems are prime locations for convective heat transfer to occur.

Radiation is the process of heat transfer by electromagnetic wave motion. All bodies emit, or give off radiant energy;- the rate at which they do so is dependent on their surface temperatures and their emissivities. Radiation is the key mechanism responsible for the transfer of heat from interior room surfaces to window glazing. Conversely, the admittance of solar radiant energy through window glazing is the basis for passive solar heating.

## 2.2 Heat Loss Through Windows

Heat losses through windows can be broadly categorized as thermal heat tranfer losses, and infiltrative/exfiltrative losses. Thermal losses occur when heat impinges on a window assembly, and subsequently passes through its components to the exterior environment via conductive, convective, and radiative processes. Infiltrative/exfiltrative losses occur when cold air flows into a building (infiltration), or warm air flows out of a building (exfiltration) through cracks and openings around the window sash and frame. Such air movement is a result of pressure differentials across the building envelope.

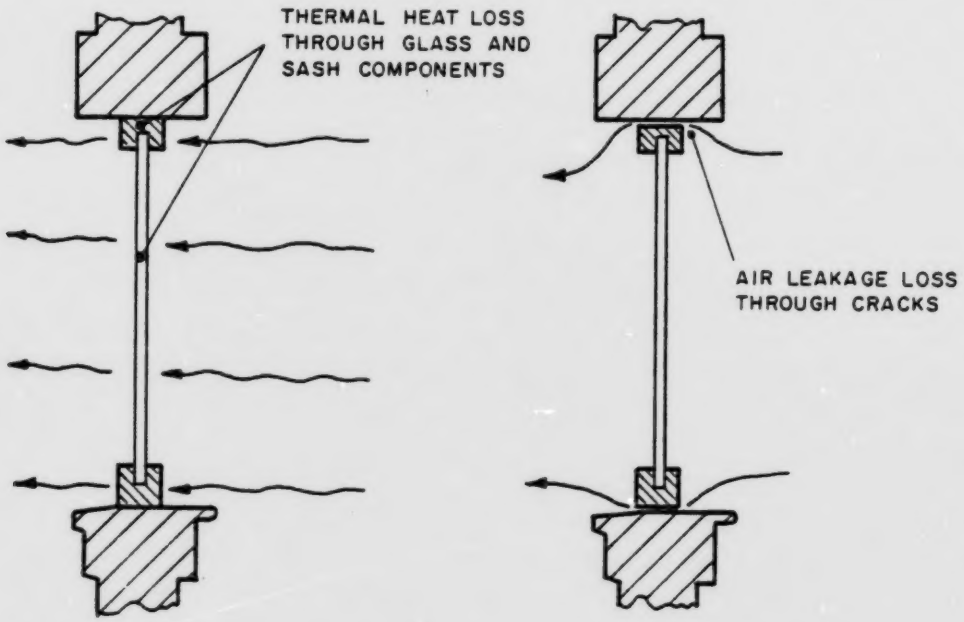



FIGURE I. MODES OF HEAT LOSS THROUGH WINDOWS

2.2.1 Infiltrative/Exfiltrative Losses

Air leakage around windows is a matter of concern because it can affect an interior environment in many ways. It can significantly increase winter heating and summer cooling loads, it can induce uncomfortable draughty conditions around windows, and it can make difficult the maintenance of controlled levels of relative humidity. Window air leakage can also affect the performance of window systems themselves with respect to rain and dust penetration, and the occurrence of condensation between panes of glazing.

Air infiltration and exfiltration occur when pressure differences exist across the building envelope. Such pressure differentials result from wind action over and around the building, air density variations caused by the differing temperatures of indoor and outdoor air, and the operation of building heating and ventilating equipment.

The resistance of a window unit to air leakage is primarily dependent on the presence and nature of cracks in the window assembly. Cracks occur whenever an operating sash contacts a window frame, or another sash. Depending on workmanship, cracks may also be present at the joint between the window frame and surrounding construction. Air flow resistance through a given length of crack increases as the cross-sectional (profile) path length through the crack increases, and as the crack width, or clearance, decreases. Hence, proper alignment of mating surfaces in the window unit, and effective performance of latching and/or locking mechanisms, are two necessary prerequisites for air leakage resistance.

The relative air-tightness of various types of windows has not been well established. Generally though, casement and awning windows exhibit superior resistance to air leakage than sliding types, including double-hung windows. This can generally be attributed to the enhanced sealing pressures provided by the

latching mechanisms associated with casement and awning windows. Vertical and horizontal sliding windows are restricted in sealing pressures simply because increasing tightness results in more difficult sash operation. (1) (Figure 2)

In Canada, air leakage criteria for a variety of window types have been established by the Canadian General Standards Board and the Canadian Standards Association. Current standards specify maximum allowable air leakage rates (expressed as cubic metres per second per metre of crack length) under specified test conditions. Conformance to these standards is generally required for CMHC acceptance of window assemblies.

The tightness, or resistance to air leakage, of any window arrangement can usually be enhanced through the use of weatherstripping. Weatherstripping is any material or device that can be positioned between the window sash and frame to decrease crack clearance or increase the air flow path length without restricting the operation of the window sash. Care must be taken in selecting a product that is both durable and capable of convenient replacement.

Caulking may also be used to effectively fill and seal cracks between immovable components in a window assembly. Such material should remain elastic and not dry or crack upon aging.

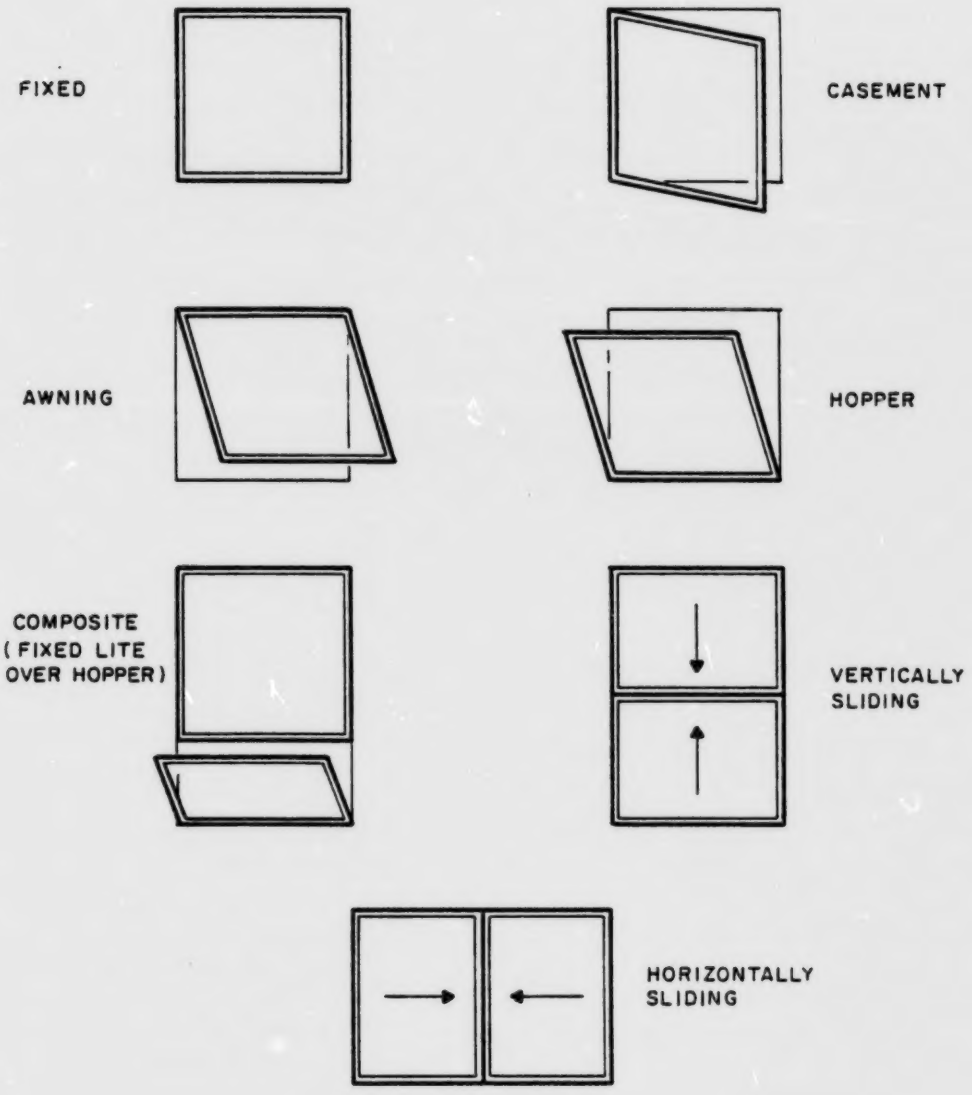



FIGURE 2. COMMON TYPES OF WINDOWS.

2.2.2 Thermal Heat Transfer Losses

The rate of heat transfer by conduction through a material is directly proportional to the temperature differential across the material, and inversely proportional to the thermal resistance of the material

$$q \propto \frac{\text{Temperature difference}}{\text{Thermal resistance}}$$

Thus it follows that for a unique set of conditions, (eg, indoor temperature of 21°C, outdoor of -12°C) the amount of heat transmitted through various components in a building enclosure will be indirectly proportional to the thermal resistances of the components. Windows typically offer significantly less resistance to heat flow than surrounding constructions, hence they transmit significantly more heat than other elements in the building envelope.

The overall thermal resistance of a single-pane window is approximately 0.16 $m^2.{}^oC.W^{-1}$. This value is derived from three components: the resistance of the pane of glass itself, and the resistances of air films which cling to the interior and exterior surfaces of the glass.

The thermal resistance of the sheet of glass is very small, in fact, negligible. This is because glass, with a thermal conductivity of approximately 1.0 $W.m^{-1}.{}^oC^{-1}$ is a relatively good conductor of heat. Most of the window's resistance is in fact provided by the interior and exterior air films, where radiative and convective heat transfer processes occur. These processes are significantly affected by the velocity and direction of air flow across the window's surfaces. Thus differing surface resistances are provided by the exterior air film, which is subjected to forced-air motion by wind, and the interior air film, which is subjected to natural convection.

In the ASHRAE Handbook of Fundamentals,( 2) surface film resistances are tabulated for various conditions. For winter conditions, a design wind velocity of 24 km/h is considered, and the corresponding exterior surface film resistance is RSI 0.03. For summer conditions, design wind velocity is reduced to 12 km/h, and the corresponding outside surface resistance is RSI 0.044. For natural convection at the inner surface of the window, a representative interior surface film resistance is RSI 0.12.

The overall thermal resistances derived from these component resistances are shown in Table I.

TABLE I

The Coefficients of Thermal Resistance of Components in a Single-Glazed Window Assembly

| Component | Thermal Resistance ($m^2.^oC.W^{-1}$) | |
|---|---|---|
| | Winter | Summer |
| Exterior Air Film | 0.03 | 0.04 |
| Interior Air Film | 0.12 | 0.12 |
| Window Glass | 0.00 | 0.00 |
| Total Resistance | 0.15 | 0.16 |

In many instances, natural convection does not occur at the interior surface of a window. For example, when a supply air grille or radiator is located directly below a window, air will sweep the interior glass surface. This reduces the thermal resistance provided by the window due to the increase in convective heat transfer at the interior surface.

2.2.3 Condensation Problems

Condensation will occur on an interior window surface whenever the surface temperature falls below the dew-point temperature of the room. With a thermal resistance of 0.16, a single glazed window is often the component of least thermal resistance in a building envelope. It will likely have the lowest inside surface temperature, and will therefore determine the practical limit of humidity for interior space in winter.

Table 2 shows that with single glazing, relative humidities above 25% cannot be maintained with outside temperatures below -7°C without excessive condensation. (3) In Canada this is a serious limitation, since winter outdoor temperatures frequently fall far below this figure.

To overcome this problem, heating units providing a degree of forced convection over the interior window surface may be employed. This course of action will increase the window surface temperature as well as the adjacent air surface temperature, and will thus raise the maximum permissible humidity level in the enclosure. However, forced convection will substantially decrease the thermal resistance of the window, and heat losses through the single glazing may increase by as much as 50 to 70%. (3)

TABLE 2

Maximum Humidities for No Window Condensation and Corresponding Inside Surface Temperatures*

| Outdoor Temperature | Surface Temperatures and Relative Humidities with Inside Temperature at 21°C | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Single Window | | | | Double Window | | | | Triple Window | | | |
| | 24 km/h wind | | no wind | | 24 km/h wind | | no wind | | 24 km/h wind | | no wind | |
| | Temp. °C | R.H. | Temp. °C | R.H. | Temp. °C | R.H. | Temp °C | R.H. | Temp. °C | R.H. | Temp. °C | R.H. |
| 4 | 8 | 44% | 13 | 59% | 15 | 68% | 16 | 73% | 17 | 78% | 18 | 81% |
| -7 | 0 | 24% | 7 | 41% | 11 | 53% | 13 | 61% | 15 | 68% | 16 | 71% |
| -18 | -8 | 12% | 2 | 27% | 7 | 41% | 10 | 49% | 12 | 57% | 13 | 61% |
| -29 | -17 | 6% | -4 | 17% | 3 | 32% | 7 | 39% | 10 | 49% | 11 | 53% |
| -40 | -26 | 2% | -10 | 10% | -1 | 23% | 3 | 31% | 7 | 41% | 9 | 46% |

* Adapted from:

A. G. Wilson, "Condensation on Inside Window Surfaces", Canadian Building Digest, CBD #4, April 1960.

## 3. REDUCING HEAT LOSS THROUGH FENESTRATION

Reducing heat loss through fenestration involves retarding the conductive, convective, and radiative heat transfer processes that occur whenever temperature gradients exist between the interior and exterior environments. This can be accomplished by enhancing the insulative properties of window assemblies with additional layers of glazing, reflective films and coatings, and insulating devices such as shutters and shades.

### 3.1 Enhanced Glazing Systems

Heat transmission through a multiple-glazed window system is impeded by the presence of entrapped air spaces, which contribute to the thermal resistance of the assembly.

Air-space thermal resistance depends primarily on three factors:

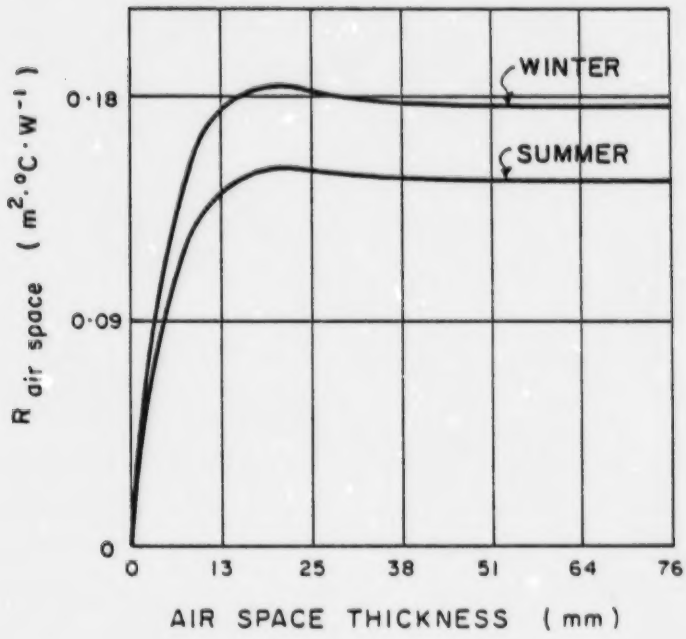
- the thickness (or width) of the air space;
- the temperature of the air in the space; and
- the nature of the surfaces that enclose the air space.

Conductive and convective heat transfer processes play an important role in establishing the relationship between air space resistance and thermal resistance. Heat transfer by conduction is reduced when the heat flow path is long; thus a wide air space is desirable to lessen conductive heat loss. With convection, however, a narrow air space is necessary in order to impede the circulation of air and thus reduce convective heat transfer.

For a vertical air space through which heat flow is horizontal, it has been found that the optimum resistance of the air space is attained with an air space thickness of approximately 16mm. At thicknesses less than this value, conductive heat transfer is significant; while at thickness greater than 16mm, convection predominates. At thicknesses exceeding 32mm, the combined heat transfer by conduction and convection is practically independent of air space thickness, and the thermal resistance of the air space can be considered constant at approximately RSI 0.18. (4)

Air temperature is the second factor that affects air space resistance. Increased thermal resistance is achieved at lower mean air temperatures, hence multiple-glazed window assemblies will exhibit slightly higher thermal resistances in winter than in summer.

Air space resistance also depends on the nature of the glazing materials that enclose the air space. By altering the absorptive and emissive properties of the glazings, radiative heat transfer across the air space can be modified such that the thermal resistance of the air space is enhanced significantly. This topic is discussed more thoroughly in section 3.2.




* ADAPTED FROM :
J.K. LATTA , " WALLS, WINDOWS AND ROOFS FOR THE CANADIAN CLIMATE ", SPECIAL TECHNICAL PUBLICATION No.1 OF THE DIVISION OF BUILDING RESEARCH, NATIONAL RESEARCH COUNCIL, OTTAWA, OCTOBER 1973.

FIGURE 3. VARIATION IN THE THERMAL RESISTANCE OF AN AIR SPACE WITH THICKNESS.*

3.1.1 Storm Windows

The addition of a storm window to a single-glazed window is a simple and effective means of creating a double-glazed window unit. Although the width of the air space created between the two panes of glazing is generally greater than the recommended optimum air-space width of 16mm, the improvement in thermal resistance achieved with this conventional arrangement is nevertheless almost on par with that provided by a sealed, double-glazed insulating unit.

Traditional storm windows are glass units affixed to the exterior frame of a window. Removable types are designed to be installed in the fall, and removed in the spring. Permanent storm windows comprise both screening and glass in the same assembly, and therefore are serviceable year-round. They generally have metal frames, and hence must be custom-made.

Storm windows need not be fashioned from glass, nor do they have to be installed on the exterior of a window. The use of both flexible and rigid plastic glazings for storm windows is increasing in popularity as is their placement on the interior side of the window.

Plastic glazings are generally easier to handle and install than glass, and are often lower-priced as well. However, certain plastics may be less transparent than glass, and may also prove less durable than glass due to ultraviolet degradation.

Polyethylene film is a flexible plastic material commonly used for storm windows because of its very low cost. However, it deteriorates rapidly in sunlight and at best will last only two years. It is is also highly transparent to long-wave room-temperature radiant energy. Clear flexible vinyl is more durable than polyethylene, and also more resistant to infrared radiation transmission. Its superior qualities are reflected in its higher cost.

Rigid plastic glazings include acrylics, glass fiber-reinforced polyesters, and polycarbonates. Acrylic sheeting is a popular choice for storn windows, as it offers durability, transparency, and resistance to infrared transmission. Glass fiber-reinforced polyesters and polycarbonates generally lack transparency, hence their use for residential windows is limited.

An interior storm window can be attached to a window frame with single-sided tape, double-sided tape, adhesive strips, or magnetic strips. Care must be taken to effectively seal the frame to prevent air leakage and possible condensation problems.

Condensation Problems

Moisture condensation in multiple-glazed window units can be a serious problem since the space between glazing layers is usually inaccessable and condensed moisture cannot evaporate readily or be wiped off. Accumulated moisture can reduce visibility through the window, and can lead to the deterioration of window sash and frame components. Repeated wetting and drying of common soda lime glass can also promote scumming, the deposition of a cloudy white film on the glazing caused by the leaching of sodium salt from the glass.

Moisture condensation on the inner side of a storm seal commonly occurs when a storm sash is added to a poorly - weatherstripped window. In this instance, moisture-laden air from the interior environment enters the space between the interior and storm sashes more quickly than it can exit, enabling accumulated moisture to condense on the cooler storm sash. This condensation problem can usually be resolved by thoroughly weatherstripping the interior window sash, thus insuring that the inner sash is tighter than the outer storm sash.

"Weep holes' may also be incorporated into a window frame or storm sash as a means of 'venting' the window air cavity. While advantageous in that they allow moisture to pass quickly out of the window, weep holes may contribute to the deterioration of wooden window frame and sash components. Also, if excessive venting is provided, the temperatures of the window air space and interior glazing

surface will be appreciably lowered, possibly to the point where condensation will occur on the interior glass surface of the inner sash. Heat loss through the window will be lowered.

3.1.2 Hermetically - Sealed Units

Hermetically-sealed, multiple-glazed window units have been used in Canada for many years. Their availability dates back to the late 1940's, when sealed double-glazed assemblies were first introduced and marketed primarily on the basis of their inter-pane condensation control features. Since then, sealed double-glazed units have acquired notoriety as "insulating glass," and with increased demands for energy efficiency in building envelope construction, their use has escalated. Efforts have also been focussed on the development of triple, and even quadruple-glazed windows; although the use of these units has been somewhat limited due to their relatively high costs.

Hermetically-sealed multiple-glazed units are preassembled units comprising panes of glass mounted in parallel in the same sash, and separated by dehydrated air spaces. Generally, they can be classified into three categories:

- Type I: Spacers of lead are bonded to the glazing by a unique soldering technique. Prior to sealing, the air spaces are purged with dry air.
- Type II: These units have all-glass edges. As with Type I units, an air purge is used to dry the air spaces.
- Type III: The panes of glass are sealed to aluminum, steel, or polyvinyl chloride spacers with an organic sealant such as polysulphide, butyl, or other synthetic, rubber-based material. The spacers are generally hollow, and contain a dessicant such as silica gel or molecular sieves. (5)

Units manufactured today are commonly of the Type III variety. While Type II units with all-glass edges would be preferable due to (i) the absence of metal in the assembly, and (ii) the excellent seal attainable; high production costs have inhibited their use.

The thermal performance characteristics of multiple-glazed units are shown in Table 3.

TABLE 3

The Coefficients of Thermal Resistance of
Multiple-Glazed Windows and Storm Windows*

| Window Type | Thermal Resistance ($m^2.^oC.W^{-1}$) Winter | Summer |
|---|---|---|
| Sealed, double-glazed unit | | |
| 5mm air space[1] | 0.28 | 0.27 |
| 6mm air space[1] | 0.30 | 0.29 |
| 13mm air space[2] | 0.36 | 0.32 |
| Single-glazed window plus storm window | | |
| 25-100mm air space[1] | 0.35 | 0.35 |
| Sealed, double-glazed window plus storm window 25-100 mm air space | 0.49** | 0.46** |
| Sealed, triple-glazed unit | | |
| 6mm air spaces[1] | 0.45 | 0.40 |
| 13mm air spaces[3] | 0.57 | 0.45 |

[1] 3mm glass

[2] 6mm glass

[3] Window design: 6mm glass - 3mm glass - 6mm glass

* Adapted from:

"1977 Fundamentals", ASHRAE Handbook
Published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. New York, N.Y.

** Not published in ASHRAE Handbook.
Obtained by summation of component resistances.

A common misconception is that sealed, double-glazed units provide superior thermal resistance to that attainable with conventional double-glazing arrangements. As shown in Table 3 , there is little difference between the coefficients of thermal resistance of sealed double-glazing and that of a conventional storm window arrangement. The thermal advantage is, in essence, negligible.

There are, however, two key advantages associated with the use of sealed double-glazed units: first, the number of glazing surfaces requiring cleaning is reduced to two; and second, with intact seals, the occurrence of condensation between the layers of glazing is virtually eliminated.

Factors Contributing to the Failure of Factory-Sealed Window Units

The effective performance of factory-sealed glazing units depends upon the presence of a dry air space between the layers of glazing. Under normal conditions of exposure, this situation is difficult to maintain, since a number of factors contribute to the gradual deterioration of the hermetic seal:

- Fluctuations in temperature and barometric pressure induce the cycling of pressure differentials between the air space and the atmosphere. (5) This cycling can distort the glazing and impose stresses on the spacer and the seal. Since pressure fluctuations increase with increasing air-space thickness, air-space widths in sealed units are usually limited to 13mm.
- Differences in the thermal expansion/contraction coefficients of components in a sealed unit can cause differential movements to occur, thereby inducing stresses in the glazing, spacer material, and sealant. Careful integration of all components in a sealing system must therefore be exercised

in order to avoid glass breakage and excessive strain in the sealant.

- Shrinkage and hardening of sealant material may occur with time.
- Chemical imcompatibility between sealing materials and other components in the window assembly may also lead to sealant deterioration.

Failure of the hermetic seal will cause the dew-point of the air space to rise. The rate at which it does so depends on the extent of seal failure, and the environmental conditions to which the window unit is exposed. Ultimately, condensation will occur on inaccessible glass surfaces, causing scumming and clouding. At this point, it then becomes necessary to replace both glass panes of the affected assembly. (6)

The life expectancy of a hermetically-sealed unit is thus limited by the durability of the seal. Most glass manufacturers will guarantee hermetically-sealed units against seal deterioration and corresponding visual obstruction for a period of five years.

## The Use of Noble Gases in Sealed Windows

Research is currently being conducted to establish the feasibility of using heavy noble gases, such as a krypton, in sealed glazing units. It is believed that such gases could effectively reduce overall heat transmission between the glazing layers by reducing convective heat transfer across the enclosed gaps. Reduced sound transmission might also be achieved.(7)

Chemical compatibility between gases and glazing sealants is of primary concern, and is currently a chief area of investigation. Availability and cost of appropriate gases are also factors yet to be established.

Heat Loss Through Frames and Sash

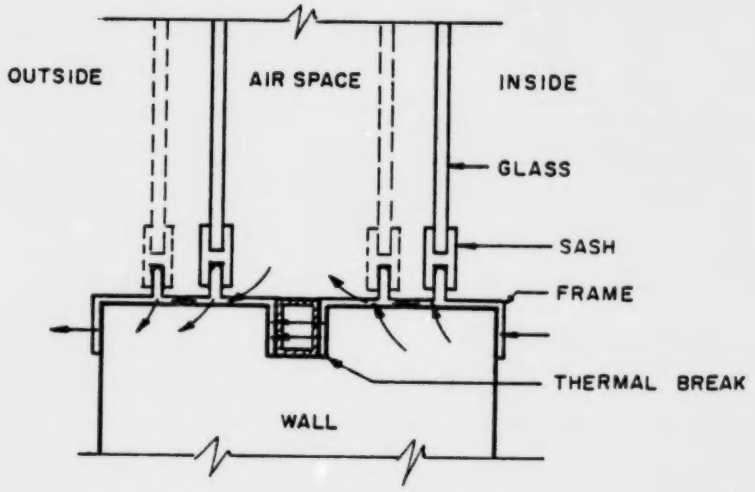
Heat transmission through multiple-glazed windows may be influenced significantly by the characteristics of frame and sash components. Careful consideration must be given to the thermal properties of frame and sash materials, as well as the manner of assembly of these components, if the thermal advantages of multiple glazed windows are to be fully developed.

For optimum thermal performance of multiple glazed windows, the interior surface temperatures of frame and sash components should be equal to, if not higher than, the minimum surface temperature of the glass. This situation normally will occur when frames (and sash) are constructed of wood or other low conductivity material, since the thermal resistance provided by the frame will be equal to, if not greater than, the thermal resistance afforded by the glazing and associated air spaces. However, if frames and sash are constructed of metal which continuously bridges the interior and exterior surfaces of the window assembly, heat loss through the frame will be considerable, and interior surface temperatures accordingly will be lower than glass surface temperatures. This situation may impose severe limitations on levels of humidity maintained in the building.

Thermal Breaks

Excessive heat loss due to highly conductive metal frames and sash can be reduced by the incorporation of thermal breaks into the framing and sash material.

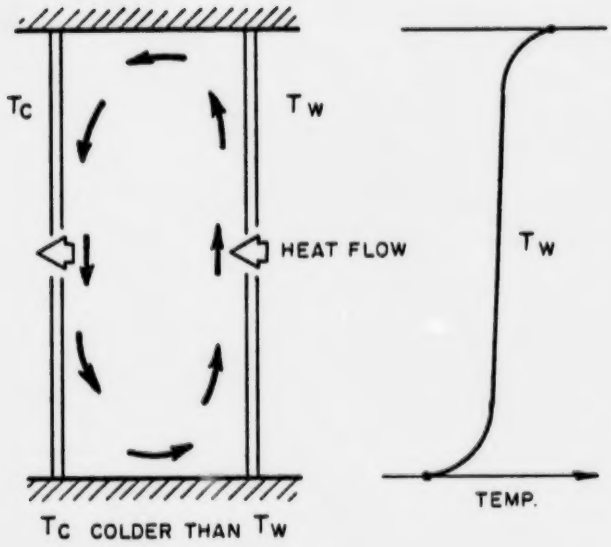
A thermal break is an insulative element which separates interior and exterior metal frame/sash components. Box sections of rigid vinyl or PVC are commonly employed as thermal breaks. Wood sections may also be used. These materials are sufficiently rigid to permit the two frame or sash components to act as a single structural unit when fastened together. (Figure 4)




A.G. WILSON and W.P. BROWN, "THERMAL CHARACTERISTICS OF DOUBLE WINDOWS", CANADIAN BUILDING DIGEST No. 58, OCTOBER 1964.

FIGURE 4. HEAT FLOW THROUGH FRAME OF DOUBLE WINDOW WITH THERMAL BREAK.

The required thickness of a thermal break is dependent primarily on the overall thermal resistance of the glass/air space assembly. As a first approximation, the thermal resistance of a full thermal break should be equivalent to the resistance of the air space(s) in the window assembly. (8) This requirement may be lessened somewhat since the surface temperature of glass at the bottom of a window pane is lower than the average glass temperature due to internal convection. (Figure 5)



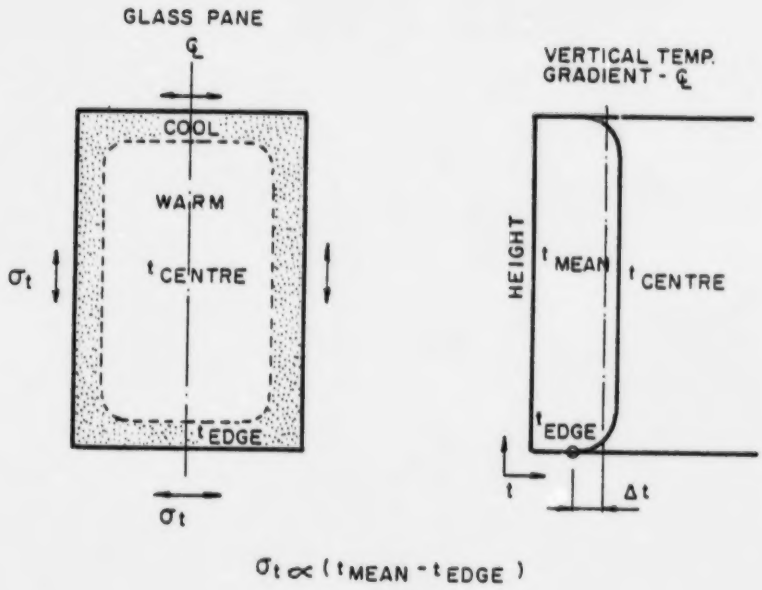

* J.K. LATTA, " WALLS, WINDOWS AND ROOFS FOR THE CANADIAN CLIMATE ", SPECIAL TECHNICAL PUBLICATION No. 1 OF THE DIVISION OF BUILDING RESEARCH, NATIONAL RESEARCH COUNCIL, OTTAWA; OCTOBER 1973.

FIGURE 5. EFFECT OF CONVECTION IN AN AIR SPACE ON THE WARM SIDE SURFACE TEMPERATURE.

Edge heat losses are of particular concern in sealed, multiple-glazed units, since the spacers and edge surrounds commonly used in their assembly are of limited thickness and generally constitute low-resistance heat flow paths. The problem is most pronounced in Type III units that incorporate aluminum or steel spacers. These metal components 'bridge' the window air space, allowing rapid heat conduction at the window's edges. In this way, the insulative barrier provided by the air space is effectively circumvented.

In very cold weather, localized heating of the inner glazing may occur, whereby the mean temperature of the glass pane is warmer than the edge temperature. This situation generates tensile stresses at the edges of the glass pane. (Figure 6) When these thermal stresses are augmented with other tensile edge stresses, the edge strength of the glass may be exceeded. Glass breakage, commonly termed "cold weather breakage", will then occur. (9) It is therefore essential that, in the design of sealed glass units, factors be introduced to reduce the potential for such breakage. Careful consideration must be given to window frame and glazing details so that edge and spacer temperatures can be maintained at temperatures close to those at the centre of the pane.

The improved thermal resistance achieved with multiple-glazed windows generally results in higher interior surface temperatures and allows for the maintenance of higher levels of relative humidity in the enclosure. (This is evident from the figures presented in Table 2). However, this advantage is realized only if metal frames and sash incorporate thermal breaks. Otherwise, condensation will occur on the metal frame and sash components at approximately the limiting relative humidities for single glazing.




J. R. SASAKI, "POTENTIAL FOR THERMAL BREAKAGE OF SEALED DOUBLE-GLAZING UNITS", CANADIAN BUILDING DIGEST No. 129, SEPTEMBER 1970.

FIGURE 6. THERMAL TENSILE STRESSES IN WINDOW GLASS.

## 3.2 Reflective Films and Coatings

Window glass is opaque to long-wave room-temperature infrared radiation. Thus, when heat emitted from interior surfaces impinges on window glazing, it is absorbed by the glass. The absorbed energy then warms the glass slightly, and subsequently is re-radiated to the exterior.

Window radiative heat transfer at infrared wave lengths can be effectively suppressed through the use of reflective materials which redirect radiant energy back into the interior space. Suitable reflective materials include foil sheeting and polyester plastic film with low emissivity, metallic coatings, commonly called "sun-control films". When applied to the face of an existing window lite, these materials can enhance the thermal resistance of the window.

When a low-emissivity, reflective coating such as a thin layer of gold or aluminum, is applied to one of the glass surfaces that encloses an air space, the resistance of the air space can be increased significantly. For example, with a 13 mm air space, the resistance can be more than doubled, making the single-coated double-glazed assembly as effective as uncoated triple glazing. Applying the coating to both glass surfaces facing the air space only marginally increases the resistance over that obtained with a single coating. (10)

Reflective coatings and films offer several advantages in addition to their energy saving properties. They can reduce fading of interior surfaces caused by ultraviolet radiation, they can reduce glare, and they can strengthen normal window glass. (11) However, there are also disadvantages associated with their use. Visible light transmission may be reduced significantly, the bond between film and glass may deteriorate, and glass breakage may occur due to the differing thermal expansion/contraction coefficients of the film and glass.

Reflective film can generally be purchased by homeowners and applied to existing windows using appropriate adhesives and following manufacturers' recommended installation procedures. However, certain brands may require application by an authorized installer.

Heat Mirrors

Research efforts presently are being directed towards the development of heat mirror films which will readily transmit short-wave visual light but reflect long-wave infrared radiation. Such film will prove effective in suppressing radiative losses through windows in the winter, as well as radiative heat gains through windows in the summer. (12)

A heat mirror surface is formed by the deposition of very thin coatings of metallic material, such as gold or silver, on a transparent substrate such as plastic film or glass. Careful control of film thickness leads to optimization of light transmittance and infrared radiation reflectance properties.

The effective performance of a heat mirror film will depend upon its application. For example, placement of a heat mirror on a single-glazed window will not be particularly effective, since the glazing covered with the film will become very cold, and condensation may occur on its interior surface. Surface moisture may in turn reduce the reflectance of the heat mirror, and hence its resistance to radiative heat transfer. (4)

Since heat mirror films have, to date, shown only modest resistance to abrasion and corrosion, their application in semi-protected environments is desirable. Hence placement of a heat mirror film facing outdoors on an exterior pane of glass is not recommended.

Heat mirrors appear to be particularly effective when placed midway between layers of glazing. For example, with a heat mirror placed between glazings of a double-glazed window unit, a

resistance of approximately RSI 0.60 can be achieved. This represents an improvement in thermal resistance of approximately 70% over that obtained with clear double glazing. A second heat mirror applied to the interior surface of the inner pane further increases the thermal resistance of the assembly to 0.74, a figure approximating that provided by a clear, quadruple-glazed assembly. (13)

## 3.3 Movable Insulation Systems

Movable insulating devices can transform thermally inefficient windows into energy control points in a building envelope. Properly designed and managed, they can control energy transactions between the interior and exterior environments, and thereby effectively reduce window heat loss and enhance solar heat gain.

The use of movable window treatments may also influence the comfort of building occupants. When there is too great a difference between body temperature and the temperature of a nearby surface, an individual will experience discomfort due to increased radiant heat loss (or gain). Upon examination of this phenomena, researchers in England have found that people will generally feel uncomfortable near a surface having a temperature that differs from surrounding surfaces by more than $8^{\circ}C$. (14) Thus a relatively cold window surface may well be a source of discomfort for individuals. If, however, a window treatment is employed to reduce heat transmission through the window, the interior surface temperature of the window will increase, and human discomfort will be reduced, if not alleviated.

Movable insulating window treatments include interior, exterior and inter-pane shutters, shades, and draperies. Choosing an appropriate device for a particular application warrants careful consideration of the design features associated with each option.

### 3.3.1 Factors Governing the Performance of Window Insulation Systems

Factors governing the effective performance of a window insulating device include:

- thermal resistance
- operability
- attractiveness
- cost
- durability

The device should also afford protection against the occurrence of moisture condensation problems, and be safe with respect to fire, chemical toxicity, and mechanical performance.

Thermal Resistance

The thermal resistance of a window insulating device, while important, is a factor that is often overrated. As Langdon (4) states, "The high-R-value syndrome has caused some window insulation products to become thermally over-designed to the extent that ease of operation and cost effectiveness begin to suffer."

As with the addition of insulation to walls or attic space, the application of window insulation reaches a practicable limit, above which the incremental energy saving achieved with each additional R-value becomes less and less significant. Langdon suggests that when movable insulation is used approximately 14 hours per day, this limit is approached with insulation having a thermal resistance of 1.40. (4)

The thermal effectiveness of a window insulation system is reduced significantly when convective air flow loops are established around the insulative layer. As shown in Figure 7 , convection currents transport warm air from the interior room to the space existing behind the insulating material, thereby effectively bypassing the window insulation and associated air films.

If however, air space behind an insulating device is sealed from the room environment, the insulating value of the window treatment is maintained. Edge seals around movable insulating systems are therefore critical.

Sealing devices for use with window insulation can include weatherstripping, tracking assemblies, clamping mechanisms, cloth fasteners, and magnetic strips. Weatherstripping is particularly useful with rigid insulating panels, while tracking and clamping devices, and cloth fasteners, are effective with flexible thermal barriers such as shades and curtains. Adhesive-backed magnetic strips can be adapted to all types of window insulation.

In winter, it is important that an interior insulating system have a top edge seal to prevent the convective transport of warm room air into the air space behind the insulation. The top seal also prevents moisture condensation from occurring on the glazing. Edge seals along the bottom and sides of interior insulation are also recommended since leaks here can allow cold air pockets to form. In summer, when window insulation is used to reduce solar heat gain, a top edge seal is necessary if solar-heated air behind the window is to be kept out of the interior environment.

One disadvantage associated with well-sealed, thermally-effective interior window treatments is the thermal isolation imposed on window glazing. In very cold weather, this isolation causes the window glass to remain relatively cold. With the rapid introduction of heat to the cooled glazing, (either from the interior environment following removal of the window insulation, or from exterior solar radiation) tensile stresses are produced in the glass. If these stresses exceed the strength of the glass, breakage may occur.

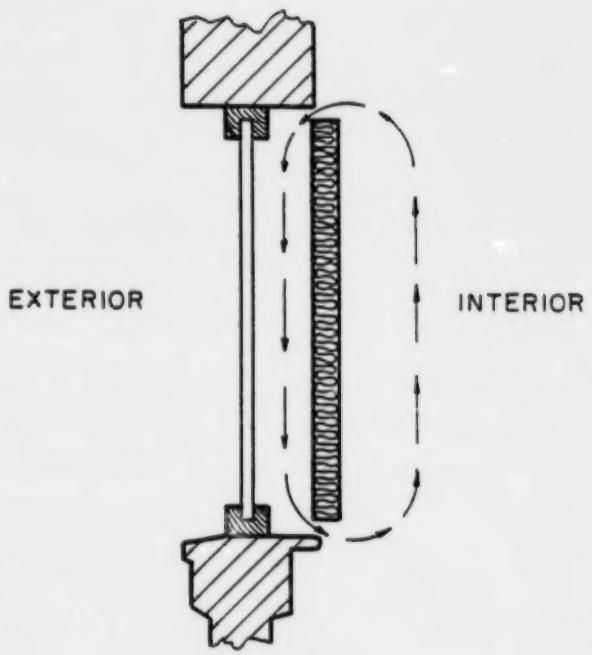



FIGURE 7. CONVECTION CURRENTS BY-PASS WINDOW INSULATION.

Operability

Most window insulation systems are manually controlled, hence ease of operation is an important consideration. Greater movability will promote continued and attentive use of a window treatment, allowing optimal energy savings to be realized.

Automatic operating mechanisms are generally more expensive than manual ones, but require only minimal attention and may be programmed to open and close at optimal times. Maintenance may, however, be costly and involved.

Attractiveness

Window insulating devices, be they internal, external, or inter-pane treatments, should complement their surroundings. Treatments that detract from the appearance of an architectural space will likely remain unused and totally ineffective.

Cost

Cost of window insulation systems vary; simple homemade treatments can be as little as $3.00 per square metre of window, while more sophisticated custom designs can be well over $100.00 per square metre. (4) With low-cost systems, payback periods of less than a year may be realized. Moderately priced insulating systems generally have payback periods of four to five years, while expensive, sophisticated assemblies may take upwards of 15 years to pay for themselves strictly with generated energy savings. (4)

When considering window insulation options on a cost-benefit basis, benefits should not be restricted to heat loss reductions but should also encompass such items as the operability of device or mechanism, the aesthetic enhancement of the living space, improved privacy, improved control of natural lighting, and the provision of shading against unnecessary heat gain in summer. The optimal window treatment will impart the most benefits per dollar invested.

Durability

Wear resistance and long life are desirable features of all window insulation systems, particularly those with long payback periods. Careful examination of elements subjected to wear, such as hinges, pivot points, edge seals, and tracks is therefore recommended when selecting a window treatment. Well designed insulating systems generally incorporate replaceable wear points.

When fabrics are used in window treatments, the effects of exposure to sunlight, heat, and moisture are of concern. Materials that exhibit good resistance to sunlight, heat, and air poluution, and that have low moisture absorption properties, are therefore most appropriate in window treatment applications.

Protection Against Moisture

Moisture migration through window insulation can lead to moisture condensation on interior glazing. This can be a particularly serious problem when insulated devices are placed over single glazing, since single-glazed glass can become very cold and frost build-up can be rapid.

To prevent moisture migration, a vapour barrier (in addition to edge seals) should be present in a window insulation system. With rigid devices such as shutters, a layer of foil sheeting can generally be incorporated into the assembly. With more flexible insulating treatments such as shades and draperies, the use of a layer of polyethylene or vinyl sheeting is recommended (4), particularly in areas of high humidity and/or very cold climates. In a more moderate environment, a curtain or shade containing a layer of nylon material would likely prove effective.

Safety

Most window insulation systems are combustible to some extent, hence fire safety is an important concern. Window insulation materials should be chosen such that they do not constitute greater fire hazards than other materials in the home. Components with high flame spread ratings should be avoided.

Insulating systems with pointed or sharp edges and hardware at eye or head level can be dangerous. Similarly, heavy devices that swing outward or upward are potentially hazardous. Caution in the use of systems with such features must be exercised.

### 3.3.2 Interior Window Insulation

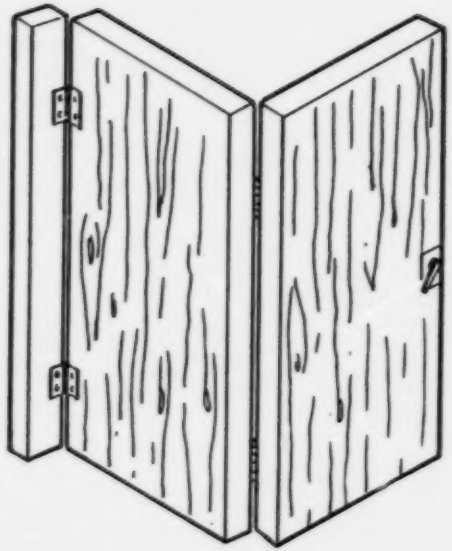
Interior window-insulating accessories include shutters, shades, and draperies.

#### Shutters

Insulating shutters are rigid, lightweight, movable panels that are placed into, or in front of, window openings when window insulation is desired. The 'pop-in' variety are positioned inside window openings, and are held in place by magnetic strips, perimeter seals, or friction against the window frame. When not in use, the panels must be stored elsewhere. 'Hinged' or 'sliding' shutters are attached to a window frame with appropriate hardware. When opened, they swing or slide to unobtrusive parking locations at the edges of the window. (Figure 8)

Shutters may be fashioned from a variety of insulating materials, including foam sheathing boards of polystyrene, polyurethane, or isocyanurate; rigid glass fibre insulation; and corrugated cardboard stock. The approximate insulating values of such materials are as follows:

| Material | Approximate Thermal Resistance (R-value) per 25 mm Thickness ($m^2.^oC.W^{-1}$) |
|---|---|
| Extruded Polystyrene Board | 0.88 |
| Expanded Polystyrene Board | 0.70 |
| Polyurethane | 1.10 |
| Polyisocyanurate | 1.40 |
| Rigid Glass Fiber | 0.70 |



HINGED SHUTTER

POP-IN SHUTTER

FIGURE 8. HINGED AND POP-IN SHUTTERS

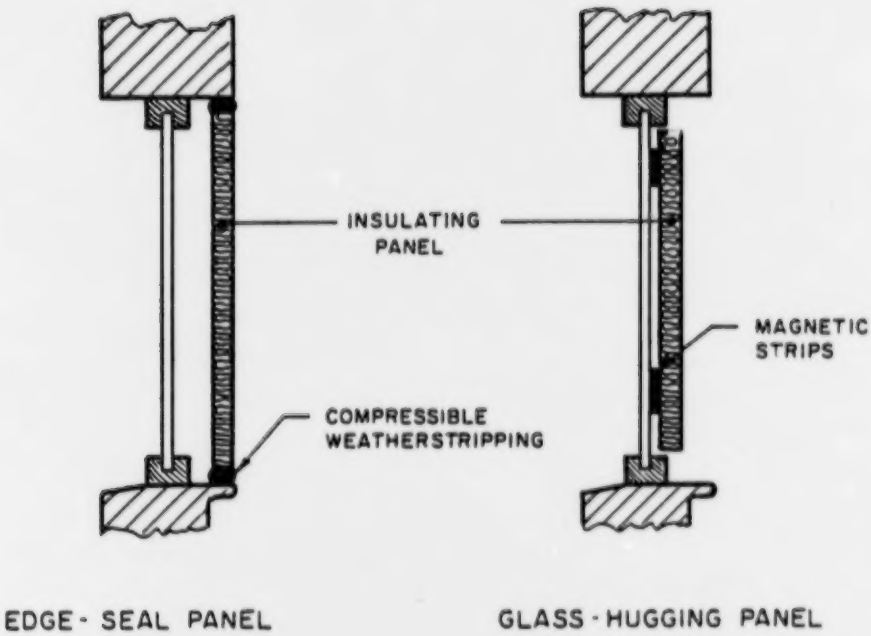



FIGURE 9. REDUCING AIR CONVECTION BEHIND POP-IN SHUTTERS.

When combustible materials are used, the application of aluminum foil sheeting to both faces of the panel is recommended (4) as a means of protecting the shutter from rapid flame spread. The foil sheeting will also effectively retard vapour flow through the material, and will serve as a reflective barrier to radiative heat transfer.

Shutters are ineffective as thermal barriers if air can convect behind and around them, short-circuiting the insulation. It is therefore important that shutter designs incorporate features to prevent such air movement.

'Glass-hugging' pop-in shutters are panels that are placed very close to the window glass surface such that only a 1 - 2 mm gap is present between the glass and the shutter. This narrow air passage inhibits air flow over the glass surface, and hence the need for additional edge seals is eliminated.

Glass-hugging shutters are held in place by mated pairs of adhesive-backed magnetic strips. This means of attachment is disadvantageous in that the strips placed on the surface of the window remain in place even when the shutter is removed; thereby cluttering the face of the window. Thus care must be taken in the initial attachment of the clips to establish a neat and regular placement pattern.

Pop-in shutters positioned further from the window glass require the use of permiter sealing devices, such as weatherstripping, to adequately seal off the air space behind the shutter from the interior environment. Such shutters are commonly called 'edge-sealed' panels.

Hinged or sliding shutters should also be well-sealed to prevent air leakage and associated condensation problems. Compressible vinyl-clad foam weatherstripping applied to panels' edges and centerfolds has been found to be an effective sealant. (4)

Shades

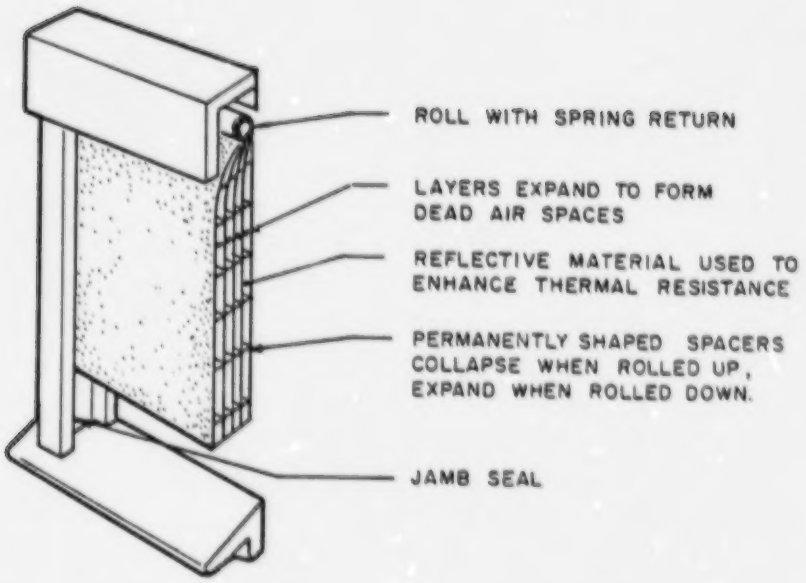
Shades are flexible window coverings that are mounted on roller mechanisms and positioned at the top of window assemblies. They are engaged and disengaged by simple pulling motions, and when not in use, they occupy minimal space; an advantage held over other window insulation systems.

Traditional window shades comprise single layers of relatively thin fabric or vinyl sheeting, positioned loosely in window openings. As such, these coverings are ineffective in reducing window heat loss. However, modern 'thermal' shades offer improved thermal resistance, and also incorporate features which reduce air flow and corresponding heat loss around the edges of the shades. Such shades may be multi-layer, expandable assemblies; fiberfill-quilted coverings; or rigid, slatted units.

In a multiple-layer shade, thin sheets of material, often reflective, form air spaces which inhibit heat transfer through the shade. Spacer strips may be used to separate the individual fabric layers and reduce and localze convective air movement between shade layers. These spacers are generally designed to collapse when the shade is raised; thus shade storage is achieved with a minimum of bulk.

Properly designed and installed a multiple-layer shade can be a very effective window insulacor. However, as with all interior insulating treatments, a permiter seal is essential for optminum performance.

Multiple-layer shades presently on the market generally provide R-values in the order of RSI 1.8 or better. One design in particular, when tested at an independent test laboratory, was found to provide an R-value of approximately RSI 3.0 when tested in conjunction with a double-glazed window. (15)


ROLL WITH SPRING RETURN
LAYERS EXPAND TO FORM DEAD AIR SPACES
REFLECTIVE MATERIAL USED TO ENHANCE THERMAL RESISTANCE
PERMANENTLY SHAPED SPACERS COLLAPSE WHEN ROLLED UP, EXPAND WHEN ROLLED DOWN.
JAMB SEAL

* Adapted from:
A. J. Hand, "Insulating Window Shade,"
Popular Science, January 1979

FIGURE 10. A MULTI-LAYER WINDOW SHADE

A fiberfill shade, commonly called a window quilt, is a multi-layer assemblage incorporating sheets of synthetic polyester fiber material sandwiched between outer layers of decorative fabric. Generally, a vapour-retardant material such as metallized plastic is also present in the assembly.

The quilted shade is mounted on a roller mechanism, which may be housed in a valence at the top of the window. Edge tracks are used to seal the sides of the shade, and weights are employed to provide a seal along the bottom edge of the fabric panel.

Fiberfill shades typically provide R-values in the order of RSI 0.7 - 1.0. The level of insulation achieved in practice is, of course, dependent on the effectiveness of the edge seals in preventing air circulation around the shades.

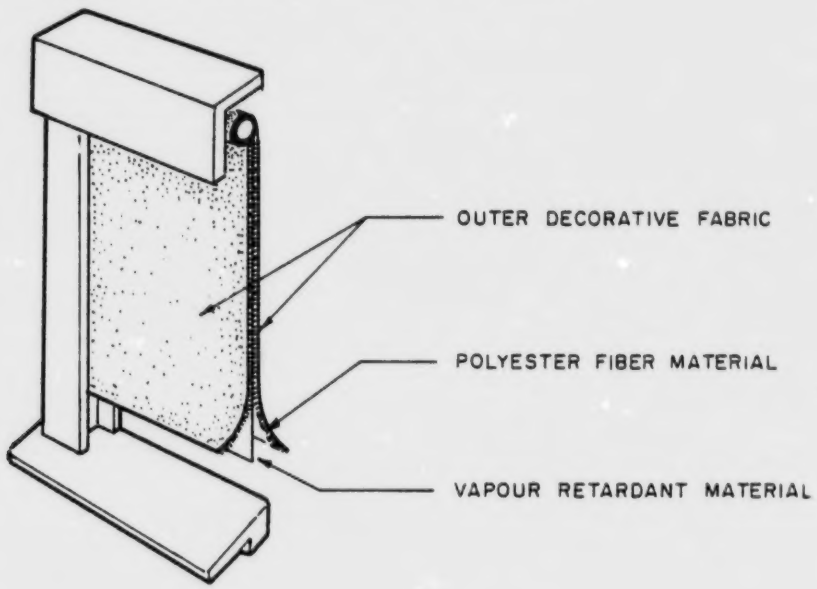



FIGURE II. A FIBERFILL SHADE

A slatted shade comprises interlocking, rigid plastic slats that roll along tracks installed in the window frame. The slats are generally hollow, insulating air pockets that interlock with precision, preventing air movement through the shade. Their alignment is maintained by the side guides, which serve as perimeter seals.

Because of its rigidity and side-track supports, a slatted shade is a popular choice for insulating skylights and slanted windows.

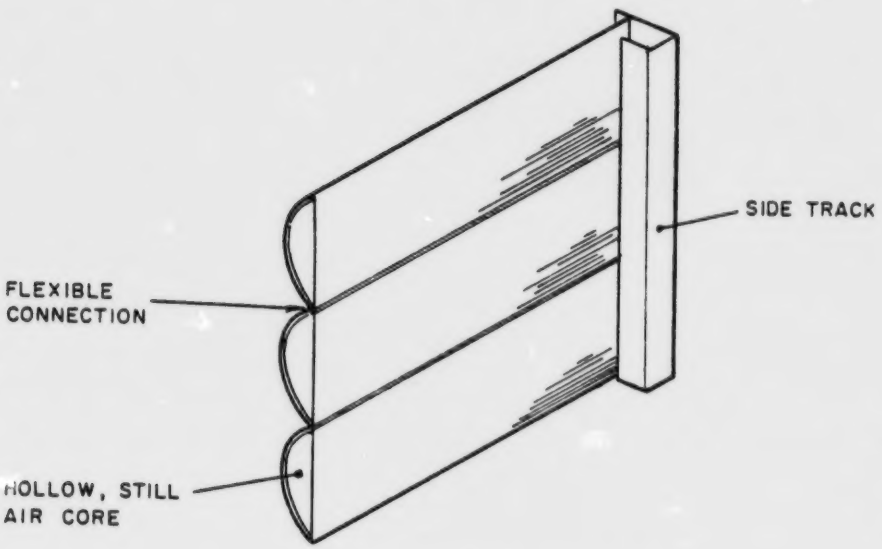



FIGURE 12. A SLATTED SHADE

Curtains

A curtain is a classic, interior design element that can also be an effective window insulating treatment if the following features are embodied in its design:

- edge seals
- air/vapour barriers
- fabric that affords resistance to heat flow.

The provision of perimeter seals between the curtain and the window frame is essential in order to prevent the occurrence of convective heat transfer between the room air and the air behind the curtain. In winter, bottom seals are especially important, since they prevent denser, window-cooled air from entering the living space. Bottom-seal options include weighted hems, magnetic strips, clamping mechanisms, elasticized cords, and bars which hold the curtain snugly against the windowsill.

A top seal is also a key requirement in winter, as it stops the entry of warm, moisture-laden air into the cool air space behind the curtain, and thereby prevents moisture from condensing on the window glass. The top seal will also prove useful in summer, when it blocks the entry of window heat into the interior. Common top seals are wooden and cloth valances.

Edge and centre gaps also require sealing if the curtain is to function as an effective thermal barrier. Edge seals can be formed by fastening the curtain fabric to the wall or window trim with small tacks, or clamping bars. Magnetic strips have also proven effective in this application. Centre seals are more difficult to establish, since it is awkward to apply pressure to the joint where the two curtain panels meet. Possible fastening options includes snaps, zippers, and tie strings; Velcro (a hook and loop, cockleburr type material) and flexible magnetic strips.

A curtain should be impervious to air and water vapour. Fabrics that prevent air flow (e.g., tightly woven materials) and materials that retard moisture migration (e.g., polyethylene or vinyl sheeting) should therefore be incorporated in the curtain design.

In order to function as an effective thermal barrier, a curtain should also afford resistance to heat flow . This can be achieved through the use of thick, tightly-woven material, fibrous filler material, and reflective sheeting in the curtain assembly.

3.3.3 Inter-Pane Insulation

Inter-pane insulating treatments are devices or materials that are positioned between panes of glazing in a window system. For practical purposes, they are generally employed in window assemblies having independently-mounted layers of glass separated by an air space at least 50 mm in width. (e.g., a single-glazed window with attached storm sash).

There are two key advantages associated with the use of inter-pane insulation: (i) the insulation remains protected from degradative elements such as wind, rain, air and ice, and (ii) the insulation does not disturb or clutter the interior environment.

However, there are also problems which may arise with between-glazing designs; first, the interposed insulation, if not removable, may obstruct vision through the window and block entering daylight; and second, it is difficult to maintain a tight seal around an interior layer of glazing and still accomodate an operating mechanism for the insulation system. Lack of a proper seal may lead to inter-pane fogging and moisture condensation problems.

Windows located in rooms that are rarely occupied are ideal candidates for 'seasonal' inter-pane insulation, ie, insulation that is installed in the fall, and removed in the spring. With such windows, daylighting and view are not of particular importance, and since operating mechanisms are not required for the insulation, an effective seal can be maintained around the interior window. A variety of materials are suitable seasonal inter-pane insulators, including foam insulation boards, glass fiber batts, and polystyrene beads and pellets.

Windows that require operable inter-pane treatments may be insulated with roller shades similar to those previously described in Section 3.3.2. A roller shade faced with aluminized or reflective material will be a particularly effective insulator, since it will impede radiant heat transfer across the air spaces formed on either side of the shade.

Venetian blinds may also be placed between layers of glazing, but they are generally more effective as interceptors of solar radiation than as thermal barriers.

Beadwall, a patented invention, is a uniquely dynamic inter-pane treatment that utilizes polystyrene beads to transform a clear, uninsulated window into an opaque, insulated cavity.

When window insulation is required, polystyrene beads are blown into the window cavity until the space between layers of glazing is completely filled. When the insulation is no longer needed, the process reverses, and the insulating beads are drawn from the cavity under a vacuum and returned to a storage container. Filling and emptying operations are automatically controlled, hence the Beadwall system can be a particularly convenient insulating option. However, operational porblems may arise if the polystyrene beads become charged with static electricity and adhere to glazings, ducts, valves and storage bins. Proper application of anti-static agents to the beads is therefore necessary periodically.

The thermal performance of a Beadwall system depends upon the thickness of the insulated cavity. Polystyrene beads typically provide thermal resistance in the order of RSI 0.67 per 25 mm - thickness, hence the thickner the space between glazings, the higher the level of insulation provided.

### 3.3.4 Exterior Window Insulation

In instances where interior and inter-pane insulating treatments are deemed inappropriate, a third option, exterior insulation, is available to the homeowner.

Movable insulating devices positioned on the exterior side of windows are advantageous in that they do not obstruct or clutter interior spaces, and they do not induce moisture condensation problems on interior glazings. Depending on their design, they may even enhance the exterior appearance of the building.

Exterior insulations are, however, subjected to rigorous environmental weathering; and problems may arise with their operation if their components are not strong, durable, and weather-resistant. Exterior insulating treatments may also prove to be less convenient than other types of window insulations if their operating mechanisms are situated outdoors.

Common exterior insulating devices include rigid hinged and sliding shutters, and roll shutters.

Exterior hinged and sliding shutters are similar in design to those employed as interior insulators, but are necessarily of heavier and more durable construction. Panels generally comprise insulating cores of wood-framed foam sheathing board sandwiched between outer layers of pressed hardboard, plywood, or aluminum sheeting. The edges of a panel may also be wrapped with protective material such as aluminized foil tape to prevent the entry of moisture into the assembly.

The effectiveness of an exterior shutter as an insulating barrier is dependent on the type and thickness of insulating material used in its core. Certainly the availability of lightweight foam insulation boards having relatively high R-values per unit thickness facilitates the fabrication of energy - efficient shutters.

Roll shutters, commonly referred to as rolladen shutters, comprise rigid, interlocking, horizontal slats of extruded aluminum or polyvinyl chloride. The slats, which may be hollow or filled with urethane foam insulation, are generally not greater than 10 mm in thickness. This limitation allows for shade storage with a minimum of bulk.

Slatted shutter systems to date have exhibited relatively low R-values. This is primarily due to the thermally-unbroken configuration of the shutter slats, as well as their limited thickness. Design modifications are therefore in order if roll shutters are to compete with other insulating treatments on a thermal performance basis. (Figure 13)

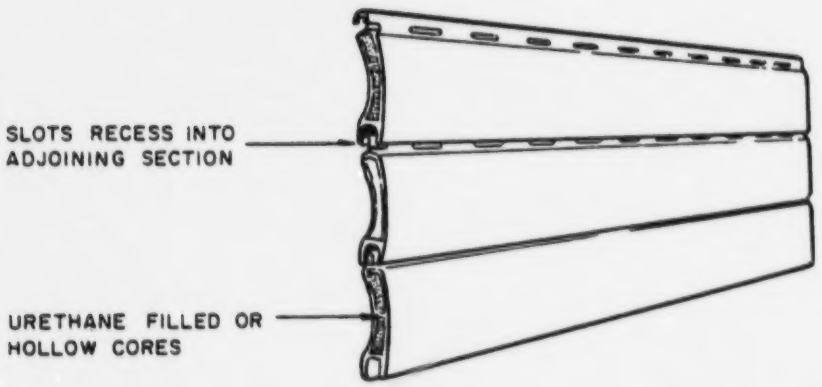



FIGURE 13. ROLLADEN SHUTTER SLATS

## 4. PERFORMANCE TESTING OF WINDOWS AND WINDOW-INSULATING DEVICES

### 4.1 Windows

The appraisal of the overall performance of a window involves the evaluation of a host of factors, including:

- the operating characteristics of the window;
- the durability of its components;
- the structural integrity of the window assembly;
- the window's resistance to water penetration;
- the air-leakage characteristics of the window; and
- the thermal resistance of the window.

Current Canadian window-testing specifications, such as CGSB and CSA publications, incorporate criteria for the evaluation of these properties; although standards' formats and requirements vary, depending on the material used in window frame and sash components. This situation poses special problems for window manufacturers and regulatory agencies engaged in the evaluation of window units that incorporate combinations of materials.

Recently, the Canada Mortgage and Housing Corporation and the Canadian Window and Door Manufacturers Association initiated the development of an omnibus window standard which will apply to all window systems, regardless of components' materials. It is intended that this standard will be performance-oriented, with criteria based on functional needs whenever possible. Thus, in any given application, comparable performances will be expected from all windows, whether their components are of wood, aluminum, steel, vinyl, or a combination of these materials.

The omnibus standard is presently in draft form, and under review by a technical committee of a standards-writing organization. It is hoped that a National Standard will be established by December 31, 1982, for possible inclusion in the 1985 edition of the National Building Code of Canada.

## 4.2 Window Insulating Devices

Performance criteria for window insulating devices have recently been established by CMHC and incorporated in a document entitled "Standard for Movable Insulating Devices for Windows". This specification serves as a basis for CMHC acceptance of movable insulating devices to be used in both new and existing residential constructions, and as such applies to a wide variety of insulating treatments, including interior and exterior shutters and shades, and inter-pane devices. As with the omnibus window standard, performance criteria are based on functional needs, and include such factors as: operability, durability, air-tightness, blow-out resistance, and thermal resistance.

## 4.3 Thermal Performance Testing Procedures

In order to establish the effectiveness of windows and window insulating devices as insulating elements, it is necessary to establish the thermal resistance and air leakage characteristics of the units. These properties generally are determined in accordance with testing procedures prescribed by the American Society for Testing and Materials (ASTM).

The thermal performance of a window assemblage may be evaluated in accordance with ASTM C236-66, "Thermal Conductance of Built-up Sections by Means of the Guarded Hot Box.

In this test, the window system is mounted in a wall panel which is positioned between a cold, weather-side chamber and a warm, room-side chamber. Instruments monitor the power required to maintain the room-side environment at a constant temperature, while window surface temperatures are recorded with thermocouples. Recorded data is then used to calculate the thermal resistance (RSI) or thermal transmittance (U) of the assemblage.

An air leakage test can be conducted following the procedure stipulated in ASTM E283-73, "Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors". As in the guarded hot box test, the window unit is mounted in a wall panel, which is then sealed into or against the open face of an air chamber. Air is supplied to or exhausted from the test chamber at a rate sufficient to maintain a specified pressure differential across the test wall panel, and the resultant air flow through the window is then measured with a flow meter.

Schematics of the facilities used to evaluate the thermal performance and air leakage characteristics of windows are shown in Figures 14 and 15.

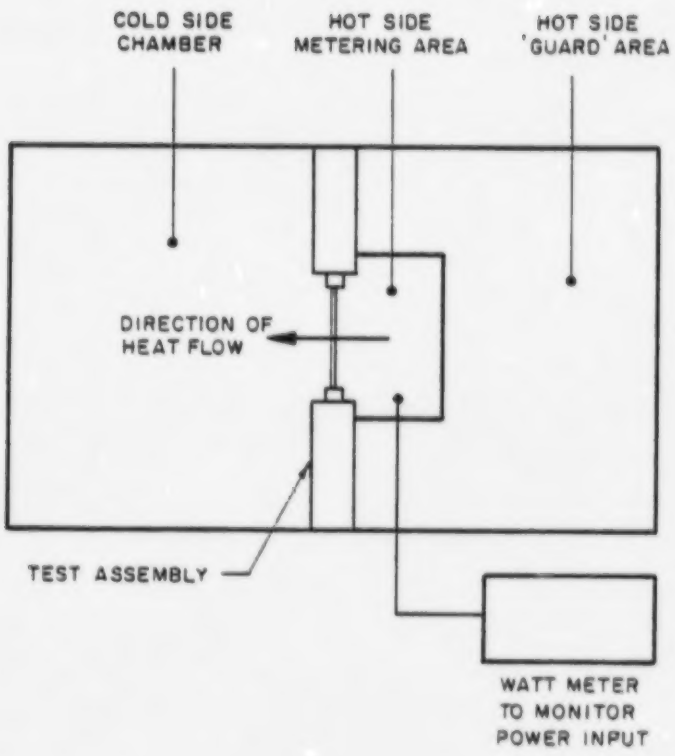



FIGURE 14. GUARDED HOT BOX ASSEMBLY.

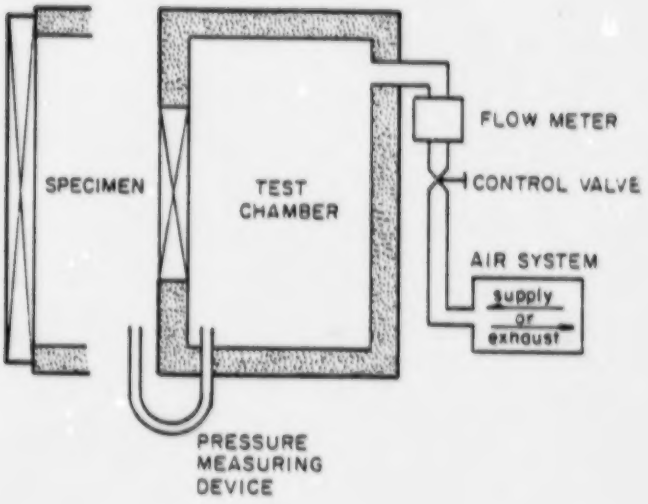



FIGURE 15. GENERAL ARRANGEMENT OF THE AIR LEAKAGE APPARATUS.

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"Movable Insulation"

Rodale Press, Emmaus, Pa.

- a comprehensive, well-illustrated guide to reducing heating and cooling losses through residential windows
- provides detailed information on insulating shutters, shades, and curtains, including helpful guidelines for do-it-yourself projects.

Shurcliff, William A.

"Thermal Shutters and Shades: Systematic Survey of Over 100 Schemes of Reducing Heat Loss Through Large, Vertical, Double-Glazed, South Windows on Winter Nights"

Cambridge, Mass.; Nov. 1977

- a detailed look at interior, exterior, and inter-pane insulating treatments for windows; with schematics provided to illustrate operating characteristics of such devices.
- presently in draft form only.

"1977 Fundamentals" - ASHRAE Handbook

Published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. New York. N.Y.

- a presentation of the technical aspects of window performance, including design heat transmission data and air leakage characteristics for a variety of window systems.

# APPENDIX A

## WINDOW TREATMENT OPTIONS

### Enhanced Glazing Systems

- Single-glazed window plus interior/exterior storm window
- Sealed double-glazed window
- Sealed double-glazed window plus interior/exterior storm window
- Sealed triple-galzed window

### Interior Insulating Devices

- Reflective films, heat mirrors
- Insulated shutters
- Roll shades
- Draperies

### Inter-pane Insulating Treatments

- 'Seasonal' insulation materials
- Roll Shades
- Blinds
- Polystyrene Beads

### Exterior Insulating Devices

- Insulated Shutters
- Roll Shades

# PART II - ENERGY CONSERVATION CRITERIA AND EVALUATION OF WINDOWS

## Development of Evaluation Criteria for Window Glazing Options and Insulating Window Treatment Devices

## 1. WINDOW RATING CONSIDERATIONS

### General

Part II of the Residential Windows Study involves the comparative evaluation of various glazing designs, configurations and window insulating systems presently available to tne consumer. For the purposes of this study, the options are categorized as follows:

(a) modifications of conventional window design and configuration, which include increasing the number of glazings or changing the type of sash/frame mechanism of the window.

(b) 'add-on' treatments, which are installed in conjunction with conventional windows to enhance one or more of the energy performance criteria. This classification encompasses enhancements such as storm panels, shutters, blinds, coatings etc. which can be operational or stationary, within the frame or glazing, and

(c) pre-fabricated, totally self-enclosed, factory built systems which are used in place of conventional windows in new or retro-fit applications. These are generally more sophisticated systems, and include such innovative ideas as 'Beadwall[1]' insulating window walls, or movable blinds inside sealed insulating glazings.

The last category of pre-fabricated, totally enclosed window systems tends to be non-standard to a large degree, and is best analyzed on an individual, product by product basis using the criteria established in this report. The rating system established is applicable to all three categories.

A comparative rating is presented for glazing alternatives in Table I, and various other insulating options in Table II.

[1] Trademark of Zomeworks Corp.

A necessary pre-requisite to this undertaking is the establishment of criteria by which selected window options can be evaluated. The procedure is described in the following sections, with the main evaluation criteria being energy and service oriented.

## 2. BACKGROUND

In order to enhance the performance of existing windows, a number of options may be incorporated into window design strategies. These options encompass materials and/or accessories designed to improve one or more of the energy-transmitting functions of windows, including solar heating, daylighting, shading, airtightness and insulation value.

Common window enhancement options include 'add-on' products such as draperies, shutters, roll shades, and blinds applied to either the interior or exterior face of a window. The more basic approach of upgrading the glazing or sash/frame system consists of adding a storm panel (fixed or removable) to a single glazing to create a double glazed window, or adding a storm panel to an existing double glazed window to create triple glazing.

The performance variation between alternative sash/frame systems is largely a function of the degree of air infiltration present. Infiltration is a greater problem where the operation of the window requires movement at the interface between sash and frame, such as in a sliding or single/double hung window configuration. It is less of a problem in configurations that rely on a positive pressure seal at the interface, such as casement or awning type windows. Also, quality of product and installation undoubtedly play a large part in all configurations in reducing air flow around and through the frame.

The ratings analysis will not further deal with the air infiltration characteristics of the frame/sash configurations, but will instead focus on the potential of the options to improve the air leakage characteristics of existing window units with which they may be installed.

## 3. WINDOW GLAZING OPTIONS: PERFORMANCE AND COST CRITERIA

Glazing units vary in terms of type, size, materials and performance. The selection of a design to best meet one's needs should be made only after a thorough review of the factors which will impact on the overall effectiveness of the window both as a component in the protective building envelope and as an architectural element. For thermal performance, these factors include: apparent thermal resistance, air tightness, and shading coefficient. In addition, operability, durability and maintenance factors should be examined, and associated costs should then be related to the advantages/disadvantages of each option to determine the optimum design scheme.

The summary tables contain both the performance parameters for single glazing and those of standard double glazing as a baseline to provide meaningful performance standards from which to rate other types of glazing options available.

### 3.1 Energy Performance Criteria

#### 3.1.1 Thermal Resistance

The R-value of a window system is a comparative measure of the insulating ability of the window. The higher the R-value, the better the window is in terms of impeding heat transmission through it.

Thermal resistance (R-value) is widely used by manufacturers, retailers and consumers alike to quantitatively define the insulating qualities of windows. However, at this point in time, procedures and equipment are not sufficiently developed to provide a totally reproducible method by which 'absolute' R-values can be measured in window units. Problems with controlling surface coefficients and boundary conditions are presently under study at the National Research Council of Canada, and it is anticipated that ultimately a

method will be developed whereby measurements of 'absolute' R-values can be made. Therefore, when the notation "R-value' is made with respect to the measured thermal resistance of windows herein, it is assumed to mean 'apparent' R-values as determined using the technology presently available.

The situation is gradually changing as window manufacturers respond to increased demands for windows with improved thermal performance. However, limitations on thermal performance are imposed by the need to use glass as a glazing material. Although highly durable and transparent, glass is an inherently poor insulating material, and must, therefore, be used in conjunction with air spaces (i.e., multiple glazing), films and coatings, or other insulating devices if enhanced thermal resistance is to be achieved. Unfortunately, such measures also serve to increase the cost of window units.

Presently, windows marketed as "energy efficient" offer apparent R-values in order of RSI 0.5. Improvements in window thermal performance will likely continue to be realized as new design techniques (e.g., heat mirror technology, inert gas spaces) are incorporated into the manufacturing process.

### 3.1.2 Air Leakage

As previously noted, the air leakage of a window unit is not affected by changing the type of glazing panel, except for the case of installing a separate storm panel which covers the frame/sash interface of the primary window. In this report, the energy conserving performance of alternative glazing options is being rated independently of any particular frame/sash system they may be mounted in and hence, air leakage has no effect on the thermal performance of glazings.

### 3.1.3 Shading Coefficient

A shading coefficient is a ratio of the total solar heat transmitted through a material to the total solar heat transmitted through 5 mm double-strength, clear, sheet glass, under identical conditions. It is expressed as a value between zero and one; with double-strength sheet glass having a shading coefficient of 1.00.

In situations where passive solar heating would prove beneficial, windows with high shading coefficients are desirable. Such is the case in winter during the daytime, when space heating requirements can be reduced with passive solar heating. Conversely, when solar heat gain serves only to increase the air-conditioning load of a building, windows with low shading coefficients are preferable.

In evaluating the performance of a window system in terms of shading coefficient, one must, therefore, consider the need for inherent shading. In the Canadian climate, windows with inherently good shading capabilities (e.g., low shading coefficients) would prove disavantageous in winter for south facing glazings, when optional passive solar heating is desired. Of more benefit would be the use of windows with high shading coefficients in conjunction with movable shading treatments that could be employed when needed.

## 3.2 Service Criteria

In the case of glazing alternatives, the units that are examined in this section use glass as interior and exterior lites, held together by various methods such as spacers, filled with desiccants, bound to the glass by polysulphides or polyisobutylene. The durability of standard soda-lime or plate window glass is well known, with the major variable being the question of durability of sealed units.

The service criteria in this section are simply rated as to the amount of time and effort a consumer would be expected to spend to keep the particular glazing option in acceptable operating condition.

Criteria for the evaluation of the convenience or durability of a particular window glazing include:

(i) accessibility of components for cleaning, servicing or maintenance;

(ii) practicality of replacing weatherstripping seals or other wear points, (i.e., storm panel);

(iii) ease of replacing damaged glazing;

(iv) sufficient design and componert strength and durability to give expected service; and

(v) durability of window glazing itself in resisting abrasion or atomospheric degradation.

3.3 Cost

A comparative evaluation of the cost of glazing design options involves consideration of initial purchase costs. These are estimated in Table I and are based on a standard sized unit with nominal dimensions of 940 mm x 1600 mm.

Costs should then be weighed against the benefits/disadvantages of each option, so that an overall perspective of the relative merits of each design is attained.

In this study, the estimated cost of purchasing (not including installation) a unit will be used as the cost factor. Maintenance cleaning and convenience cost of any unit may be reflected in the Service Characteristics section of the table as an additional serviceability rating factor which can be used in conjuction with the cost factor for overall comparisons.

## 4. INSULATING WINDOW TREATMENT OPTIONS: PERFORMANCE AND COST CRITERIA

As with glazings, there are three factors which may be used to characterize the energy performance of a window treatment:

a) thermal resistance

b) air tightness of unit, and

c) shading coefficient.

The relative importance of each of these depends upon the type of window accessory and its intended use. Interpane devices, such as adjustable shades, or polyester films for example, have no effect on the air tightness of a unit. However, they do affect the shading coefficinet and to some extent, the overall thermal resistance. Other devices, such as well sealed exterior shutters, tend to affect significantly all three factors. The disadvantages of exterior shutters will show up as a lower rating for convenience than that for an interpane device.

The effectiveness of an operable insulating device in increasing the thermal resistance of an overall window system, is dependent upon the percentage of time that the user can be expected to deploy the insulating device to its fullest potential. An option that is inconvenient or difficult to operate may not be opened and closed at the optimum times, and hence some of the thermal insulation (or solar gain) advantages may be lost.

To reflect this, a 'usage factor' has been included in Table II, which arbitrarily reflects the degree to which the thermal insulating performance of each option should be discounted from the 'nominal R-value' to give a more realistic 'effective R-value added' for each option.

## 4.1 Energy Performance Criteria

### 4.1.1 Thermal Resistance

In reviewing data on the thermal performance of a window insulating device, it is important to attempt to establish the basis for performance claims; e.g.:

(i) is the apparent R-value of the product substantiated by laboratory tests conducted in accordance with standard test procedures?

(ii) under what conditions was the product evaluated?

(iii) was the product as tested assembled or positioned in a manner similar to that encountered in actual use?

(iv) does the apparent R-value represent the thermal resistance added to a window when the window treatment is employed, or does it represent the combined thermal resistance of the window treatment and window?

(v) does the product meet the specifications of an applicable certifying body, such as CMHC, CGSB or CSA?

Consideration of these factors will enable the consumer to compare the apparent thermal performances of options on an equal basis.

For rating purposes, unless otherwise noted, a window treatment will be evaluated on the basis of "R-value-added", i.e.: the thermal resistance added to the primary window when the insulating device is employed. The determination of this value is a requirement of the Canada Mortgage and Housing Corporation's "Standard for Movable Insulating Devices for Windows".

When evaluating window insulating options it is interesting to note that studies[2] have indicated that the proximity of a given 'add-on' treatment, such as drapes or blinds, to the primary window glazing can have a more significant effect on the overall thermal resistance than the thickness of the treatment itself.

[2] Thermal-Optical Comparison of Accepted Interior Window Treatment by Richard Cran (ASHRAE)

The estimated R-values used in this study for draperies, roller blind and venetian blind devices are based on a placement of 12 cm from the glazing, which approximates conventional practices.

4.1.2 Air Leakage Around Device Perimeter

Air-tightness is essential if an interior/exterior insulating treatment is to perform effectively as a thermal barrier. A loose-fitting or open-edged device will allow warm air from the interior environment to circulate freely around it and acquire ready access to the cold window face, where conduction may then occur. The intended insulating barrier is thus effectively short-circuited.

A quantitative measure of the air-tightness of an interior 'add-on' device may be obtained by a modified air-infiltration test, in which air leakage through and around the product is determined under a specified pressure with the device mounted on a non-glazed window frame. This test yields a value of air leakage which can be expressed in terms of cubic metres of air per second per metre of device perimeter. The lower the air leakage rate, the more effective is the product in sealing the window.

In the CMHC "Standard for Movable Insulating Devices for Windows", the rate of air leakage around an 'add-on' insulating device must not exceed $12 \times 10^{-4}$ $m^3/s$ per metre of perimeter length, when tested in accordance with the specified procedure. This limit can serve as a basis for evaluating the air-leakage of treatment options and compares with $11.6 \times 10^{-4}$ $m^3$ per sec. allowable air leakage per meter of crack length for a standard vertical or horizontal sliding aluminum window.

In evaluating the air leakage of an 'add-on' accessory or device for which no air leakage test data is available, there are a number of criteria which should be reviewed, namely:

(i) provisions for edge seals; e.g. side tracks, fastening devices, weatherstripping, a weighted hem, a top valance.

(ii) effectiveness of the sealing devices:

- tightness of seal
- durability
- resiliency and flexibility of weatherstripping
- convenience

(iii) resistance to air penetration

- denseness of fabric

Positive responses to these criteria are necessary prerequisites to attaining an effective insulating accessory. In this report, air tightness assessments of the systems examined refer to their potential to increase the air tightness of the base-line single glazed window unit with the option installed. This assessment is to a large degree qualitative and also depends upon proper management of the system by the consumer for maintenance and timely deployment.

### 4.1.3 Shading Coefficient

The shading coefficient serves as a useful, quantitative measure of the solar heat gain potential of a window system. As such it is a gauge by which one can evaluate the effectiveness of a window treatment in enhancing or lessening solar heat transmission through glazing. It is important to remember that, unlike stationary systems, movable treatments are dependent upon a 'usage factor', or proper deployment at a suitable time by the consumer. This is largely an uncontrollable and unmeasureable variable that is heavily influenced by the simplicity and convenience of the system itself.

Movable window insulating accessories may be used on summer days to reduce solar heat gain, or on winter days to reduce heat loss. Generally, these shading coefficients apply to the treatments employed in combination with particular glazing systems. Hence, when comparisons of coefficients are made, one must consider the types of glazing systems used in the shading coefficient determinations.

## 4.2 Service Criteria

The ease of installing, using, and maintaining a window accessory or treatment are three factors that warrant consideration when evaluating its service performance. Since such performance features cannot be readily quantified, one must rely primarily on common sense and personal judgment to characterize the relative performance of various options. Reference to the following criteria will also aid in rating specific products:

### 4.2.1 Convenience and Usage Criteria

(i) ease of installation

(ii) accessibility and ease of operating controls

(iii) safeness with respect to mechanical performance

(iv) ease of use for ventilation and emergency entrance and exit

(v) convenience of storage

(vi) privacy when employed

(vii) resistance to fire and flame spread

(viii) compatibility of the product for decorating purposes.

### 4.2.2 Maintenance Criteria

(i) ease of cleaning product

(ii) practicality of repainting or re-covering the unit, as required

(iii) ease of adjustment or replacement of wearable parts (e.g. operating hardware, hinges, edge seals, weatherstripping).

4.2.3 Durability Criteria

(i) resistance to ultraviolet degradation

(ii) resistance to scratching, wrinkling, and/or crushing

(iii) expected lifetime of mechanisms.

4.3 Cost

In many instances, the cost of a window treatment (per unit area) decreases with increasing size. This is because a major portion of the overall cost of manufacturing a unit is a fixed cost associated with the production of operating mechanisms. For cost comparison purposes it is important that window treatments of equal size be considered. In the rating of window treatments, the approximate purchase cost is presented for treatments designed to fit a window nominally demensioned 940 mm x 1600 mm. The costs of various window treatment options are included in Table II.

## 5. GENERAL DISCUSSION

Should the reader assume a service life expectancy for a particular option, it would be possible to carry out a 'life-cycle costing' analysis from the information presented in this study. This would entail a fairly detailed analysis of variables such as present and projected rates of inflation, present and projected fuel costs, replacement and maintenance costs, and should be attempted only after verifying cost and performance data for particular circumstances.

Rating values used in the tables generally are ranges within which that type of window system can be expected to operate, and refer to properly functioning products within that classification. To compare existing windows, one would first establish the performance characteristics of the existing system in question, and then compare those values to the data presented in this report. From this exercise, an analysis of the benefits of replacing existing windows with new ones can be approximated.

A system of circular symbols is used in varying degrees of partly or fully shaded state to convey the degree to which the particular system can be expected to satisfy the rating criteria of interest where numerical data is not appropriate. It is assumed that the consumer has average interest and ability in window management, and that the equipment functions as intended.

Service criteria does not, within the context of this report, influence the rating of a given option. It does however, enable the reader to make a more complete evaluation by studying the additional information presented regarding convenience, durability and maintenance aspects of the product. It also has a direct bearing upon the assessment of the 'usage factor' which is used to discount 'nominal thermal resistances' under optimum usage conditions to actual 'effective thermal performance' ratings.

It should be emphasized that the insulating window treatment industry is a rapidly changing, somewhat unproven field, comprising a large and rapidly growing number of participants. To this end, any ratings must be regarded as a general overview of a complex situation at a given point in time. The performance data have been assembled from calculations and test data reported in manufacturers literature; calculations based upon standard ASHRAE methods; and data obtained from many other, sometimes conflicting, sources. Due to the variety of sources, these values should be used with some caution, even for comparative analysis. Condition of existing windows may also have a significant impact on installed product performance.

Suggested product categories are used in the tables to denote options of similar characteristics and footnotes are provided where possible to indicate the sources of data used. (see pg. 78)

The mention of certain company names, or brand-name products is not intended as an endorsement over other companies or similar products on the market. They have been used to indicate the type of option being examined. Before purchasing any products or materials, it is sound practice to contact the manufacturer, or his agent, directly for complete information regarding cost, performance or installation.

TABLE I

Window Glazing Alternatives

| Type of Glazing (excluding sash or frame components) | 1981 Estimated Cost* ($/m²) | Comparative Energy Performance | | | Comparative Service Performance | | |
|---|---|---|---|---|---|---|---|
| | | Thermal Resistance RSI W⁻¹ .m² .°C | Thermal Resistance R Btu⁻¹ .h.ft² .°F | Shading Coefficient (total of glazing components) | Convenience | Durability | Maintenance |
| A. Single Glazing | | | | | | | |
| A.1 Clear single glass panel (3mm) | $19.00 | 0.16 | 0.91 | 0.94 - 1.0 | ● | ● | ◒ |
| B. Multiple Glazing | | | | | | | |
| B.1 Exterior storm window (operable) plus single glazing (air space 25-100mm) | $35.-50. | 0.33 | 2.0 | 0.83 - 0.92 | ● | ● | ● |
| B.2 Fixed double glazing ie: 2 single panels with 25-100mm air space | $33.00 | 0.35 | 2.0 | 0.83 - 0.92 | ● | ● | ◒ |
| B.3 Sealed insulating glass units double glazing | | | | | | | |
| - 6.3mm air space | $63.00 | 0.31 | 1.75 | 0.83 - 0.92 | ● | ◑ | ● |
| -12.5mm air space | 65.00 | 0.33 | 2.0 | 0.83 - 0.92 | ● | ◑ | ● |
| -19.0mm air space | 65.00 | 0.37 | 2.10 | 0.83 - 0.92 | ● | ◑ | ● |
| B.4 Sealed insulating triple glazed glass units | | | | | | | |
| - 9.6/ 9.6mm air spaces | $120.00 | 0.41 | 2.33 | 0.7 - 0.82 | ● | ◑ | ● |
| - 9.6/12.6mm air spaces | 120.00 | 0.46 | 2.61 | 0.7 - 0.82 | ● | ◑ | ● |
| -12.6/12.6mm air spaces | 120.00 | 0.50 | 2.84 | 0.7 - 0.82 | ● | ◑ | ● |
| C. Multiple Glazing - Gas Filled | | | | | | | |
| C.1 Sealed insulating glass with low conductance gas fill.double glazing | | | | | | | |
| - 9.6mm air space | $80.00 | 0.34 | 1.9 | 0.83 - 0.92 | ● | ◑ | ● |
| -12.6mm air space | 80.00 | 0.42 | 2.38 | 0.83 - 0.92 | ● | ◑ | ● |

Symbols

● Good

◒ Generally acceptable for amount of effort or time required for deployment and maintenance by consumers with a reasonable level of interest in window management.

◑ Durability of sealed unit generally guaranteed by the manufacturer for 5 years.

○ Poor level of performance or unreasonable degree of effort required for operation of option.

* Note: Glazing only, does not include sash, frame or installation costs for a standard sized window with nominal dimensions 940 mm x 1600 mm (Table I and Table II).

| Description of Option | 1981 Estimated Cost ($) Net Incl. Install. | Comparative Energy Performance: Nominal R-value Added by Option SI $W^{-1}.m^2.{}^oC$ | Nominal R-value Added by Option R $Btu^{-1}.hr.ft^2.{}^oF$ | Usage Factor* | Effective R-value After Discount Usa $W^{-1}.m^2.{}^oC$ | Btu$^{-1}$ |
|---|---|---|---|---|---|---|
| A. Exterior | | | | | | |
| A.1. Exterior roll-down shutter: PVC or aluminum slats | $150. + | 0.19-0.28 | 1.1 - 1.6 | 0.67 | 0.12 - 0.18 | 0. |
| A.2 Exterior folding shutter with good edge seals - | | | | | | |
| (i) 25mm thick-extruded polystyrene/wood sandwich | $85.00 | 0.95 | 5.4 | 0.67 | 0.62 | |
| (ii) 50mm thick-extruded polystyrene/wood sandwich | 95.00 | 1.82 | 10.34 | 0.67 | 1.18 | |
| (iii) 100mm twice extruded polystyrene/wood sandwich | 105.00 | 3.54 | 20.1 | 0.67 | 2.30 | |
| A.3 Exterior storm window - covering primary window frame, (25-150mm air space) | $35. - 50. | 0.19 | 1.1 | 1.0 | 0.19 | |
| B. Between Glazings | | | | | | |
| B.1 White adjustable shades between glass eg: 'Folia Slimshade' | $65.00 | 0.978 | 0.44 | 0.75 | 0.559 | |
| B.2 'Bradwall' Jamesmorse corp. polyester beads blown into double glazed sealed unit(30mm) | $630.00 | 1.96 | 7.7 (total unit) | 0.75 | 1.02 | |
| B.3 Polyester film with vacuum deposited coating used as centre-light in triple glazing eg: '3M Sungain Window Film' | $50.00 | 0.14 | 0.79 | 1.0 | 0.14 | |
| C. Interior | | | | | | |
| C.1 Surface coatings - organic or inorganic | $60. - 75. | 0.11-0.15 | 0.6 - 0.9 | 1.0 | 0.11 - 0.16 | 0. |
| C.2 Interior shutters with good edge seals | | | | | | |
| (i) 25mm extruded polystyrene and wood sandwich | $60. - 250. | 0.91 | 5.1 | 0.75 | 0.70 | |
| (ii) 25mm polyurethane and wood sandwich | $90. - 250. | 1.25 | 7.1 | 0.75 | 0.96 | |
| C.3 Interior quilted roller shades | $100. + | 0.2-1.0 | 1.02 - 5.67 | 0.75 | 0.53 - 0.75 | 2. |
| C.4 Insulating drapes with edge seal and liner | $70. + | 0.26-0.35 | 1.4 - 2.0 | 0.75 | 0.20 - 0.26 | 1. |
| C.5 Interior storm panels (vinyl, acrylic, polyester etc.) | $7. - 21. | 0.16-0.19 | 0.9 - 1.1 | 1.0 | 0.16 - 0.19 | 0. |
| C.6 Standard venetian blinds | $20. + | 0.03-0.07 | 0.1 - 0.4 | 0.67 | 0.01 - 0.05 | 0. |
| C.7 Standard weight drapes | $80. + | 0.05-0.12 | 0.3 - 0.7 | 0.67 | 0.01 - 0.08 | 0. |
| C.8 Standard roller blinds or shades | $5. - 25. + | 0.03-0.11 | 0.1 - 0.6 | 0.67 | 0.01 - 0.07 | 0. |

* Based on percentage of time user can be expected to deploy option to its fullest potential

** See legend in Table 1.

II

Alternatives

| ded By Option Factor Applied hr.ft², °F | Air Tightness Rating of Entire System | Shading Coefficient (fully deployed) | Comparative Service Performance** Convenience | Durability | Maintenance | Comments |
|---|---|---|---|---|---|---|
| = 1.06 | Improved | 0.4 - 0.07 | ◒ | ◒ | ◒ | - manually operated from interior |
| 3.31 | Improved | 0 | ○ | ◒ | ◒ | - manual operation |
| 6.72 | Improved | 0 | ○ | ◒ | ◒ | |
| 13.07 | Improved | 0 | ○ | ◒ | ◒ | |
| 1.1 | Improved | 0.85 - 0.92 | ● | ● | ● | |
| 0.11 | Not Affected | 0.14 | ◒ | ◒ | ◒ | - shades are manually adjusted |
| 3.78 | Good | 0.1 - 0.25 Annual | ◒ | ◒ | ◒ | - electric operation, started and stopped manually |
| 0.9 | Not Affected | 0.82 - 0.85 | ● | ◒ | ● | |
| = 1.90 | Not Affected | 0.25 - 0.9 | ● | ◒ | ◒ | - should be protected from abrasion |
| 1.98 | Improved | 1 | ◒ | ◒ | ◒ | - manual operation |
| 1.11 | Improved | 1 | ◒ | ◒ | ◒ | |
| = 0.23 | Improved | 0.2 - 0.87 | ◒ | ◒ | ◒ | - manual operation |
| = 1.5 | Improved | 0.33 - 0.7 | ◒ | ◒ | ◒ | |
| = 1.1 | Improved | 0.90 | ◒ | ○ | ◒ | - susceptible to abrasion |
| = 0.28 | Not Affected | 0.33 - 0.84 | ◒ | ● | ● | |
| = 0.66 | Not Affected | 0.76 - 0.93 | ◒ | ● | ● | |
| = 0.39 | Not Affected | 0.25 - 0.70 | ◒ | ● | ● | |

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## SOURCES OF DATA - TABLES I AND II

1. ASHRAE 'Handbook of Fundamentals', 1977. (theroretical calculations, physical properties)

2. Various manufacturer's literature or information. (some test results - partially complete test descriptions)

3. 'Windows for Energy Efficient Buildings', Vol. 1, No. 2 January 1980, US Dept. of Energy. (test results, physical properties)

4. 'Consumer Reports', October 1981. (test data, costs)

5. 'Window Design Stategies to Conserve Energy', 1977 US Bureau of Standards. (test data)

6. 'Cold Frontal Attacks', Marilyn Mohr, Harrowsmith, January 1983. (test data, costs)

7. 'Movable Insulation', William Langdon. (theoretical data, test data and some practical field experience data).